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AD 25030

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 1200

LIQUID PROPELLANTS FOR GUNS

1st Partial Report

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LIQUID PROPELLANT GUNS

1st Partial Report

Task NPG-Re2d-12-1-53
Assignment NPG-Re5a-39-1-53

Copy No. 33

Classification CONFIDENTIAL
SECURITY INFORMATION

PART A

SYNOPSIS

1. The liquid propellant research program at the Naval Proving Ground is presently concerned with the development of prepackaged rounds for standard Navy guns and the study of the erosion characteristics of liquid propellants. The objective of the tests reported here was to develop a prepackaged round for the 40mm gun with ballistic properties comparable to the standard solid propellant round. The propellant used in the test was a mixture of hydrazine, hydrazine nitrate, and water.

2. The data from 143 rounds includes a tabulation of charge weight and composition, mass ratio, type of primer stock and extension tube, case assembly and free volume of case, muzzle velocity, maximum case pressures and pressures at ejection, ignition delay, and ejection time. The pressure-time oscillograms at two positions in the chamber are included for more than 90 rounds. Relations between ignition delay and free volume, peak pressures and free volume, velocity and free volume, and velocity and mass ratio are presented graphically.

3. The following conclusions are made from the results obtained on these tests:

a. The service velocity of the 40mm gun can be exceeded by as much as 150 f/s by the use of the monopropellant hydrazine without exceeding the chamber pressure of the solid propellant service charge.

b. The performance of such a liquid propellant round is of sufficient uniformity to be used in studies of gun erosion.

c. Only two modifications to standard 40mm ammunition components are required for the round developed in these tests. The case volume must be reduced and a special type of primer extension tube used.

d. The wax used in these tests to reduce the case volume is not a completely satisfactory filler. A material which adheres more firmly to the case wall will be required for automatic loading of the round. Erosion studies under rapid fire conditions are dependent on a satisfactory solution to this problem.

e. The prospects of obtaining a uniformity of performance for the monopropellant hydrazine comparable to that obtained with solid propellants are encouraging.

f. Based on the charge determined for the 40mm gun on these tests and the available data from other sources, the chamber volumes of most Navy guns appear to be 25 to 35% larger than required for liquid propellant ammunition.

g. Ignition of the propellant is affected by primer configuration and charge, propellant composition and free volume in the case.

h. Increasing the free volume in the case results in delayed ignition, increased burning rate and higher peak pressure.

i. An increase in the hydrazine nitrate content of the propellant is accompanied by an increase in burning rate, chamber pressure and muzzle velocity, and the production of secondary pressure peaks.

j. An increase in water content of the propellant is accompanied by an increase in ignition time, decrease in burning rate and velocity, and a smoothing of the pressure curve.

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PART B

INTRODUCTION

1. AUTHORITY:

The tests reported here were authorized by references (a) and (b) and conducted under Task Assignments NPG-Re2d-12-1-53 and NPG-Re5a-39-1-53.

2. REFERENCES:

a. BUORD ltr NP9-Re5a-FBW:fl of 15 July 1952
b. BUORD Conf ltr NP9-Re2d-WES:aph Ser 49271 of 17 Dec 1952
c. U. S. Naval Ammunition and Net Depot Progress Report Nos. 1 through 6 on Task Assignment NAND-13-Re2d-514-1
d. Report No. 17-1, Jet Propulsion Laboratory, California Institute of Technology
e. NAVORD No. 2255
f. NAVORD No. 2563

3. BACKGROUND:

Reference (a) established Task Assignment NPG-Re5a-39-1-53 to study erosion characteristics of liquid propellants in guns, and authorized the use of funds under this task in the development of a prepackaged liquid propellant round. Task Assignment NPG-Re2d-12-1-53 was established by reference (b). The objective of this task was to develop a prepackaged monopropellant hydrazine round for the 40mm gun and to test its performance in automatic fire. Combining the objectives of the two tasks, the liquid propellant program at the Naval Proving Ground is directed toward the development of a prepackaged round which can be used under rapid fired conditions to study the erosion characteristics of a liquid propellant.

In addition to being adaptable to automatic loading the following requirements have been laid down for this round:

a. The velocity and pressure reproducibility, storage life, and temperature range should be equal to solid propellant ammunition.

b. A velocity equal to or surpassing the standard solid propellant round should be obtained without developing excessive pressures at any point along the gun barrel.

c. The erosion rate should be less than that for a comparable solid propellant round.

d. The above results should be obtained with a minimum of modifications to existing ammunition components.

A standard 40mm barrel was chosen as the test weapon, because a gun of this size is relatively convenient to handle and instrument, and because it provides a convenient weapon for testing rounds under rapid fire.

4. OBJECT OF TEST:

The object of the tests was to develop a prepackaged monopropellant hydrazine round for the 40mm gun with ballistic properties comparable to the standard solid propellant round.

5. PERIOD OF TEST:

This report covers firings conducted between 30 July 1952 and 31 January 1953.

PART C

DETAILS OF TEST

6. DESCRIPTIONS OF ITEM UNDER TEST:

The liquid propellant used in these tests was a mixture of hydrazine, hydrazine nitrate and water. Hydrazine nitrate constituted 12.0% to 22.6% and water 4.3% to 10% of the propellant. The composition of each round is given in Table I of Appendix (B).

7. DESCRIPTION OF TEST EQUIPMENT:

The firings were conducted in a 40mm Mk A Mod 1 barrel mounted in a 6 pdr mount Mk VII, Mod 1. The barrel and mount were modified to receive dynamic pressure gages in the chamber at 3".0 and 10".0 from the breech face (See Figure 1 Appendix (A)). The Mk 1 case was used on all rounds employing the Mk 21 primer stock and the Mk 2 with the Mk 14 and 41 stocks. The projectiles were either the T1E1 or Mk 2 with their weights adjusted to 902 grams.

The pressure gages were of the expanding tube type with a 500 Ω strain gage as the pressure sensing element. This type of pressure gage has been used extensively at the Naval Proving Ground in similar applications. Gage signals were amplified by D.C. amplifiers having a flat frequency response from 0 - 50,000 cps $\pm$ 0.5 decibel with a gain of 25,000. Pressure traces were recorded from four-beam cathode-ray oscilloscopes by drum cameras having continuously adjustable speeds from 5 - 1800 rpm.

Projectile velocities were determined from measurements by chronograph counters of the time interval required for the magnitized projectile to pass between two solenoid coils. Two sets of coils were used; one set at 60 and 120 feet from the gun muzzle and the second set at 63 and 123 feet. The velocities recorded in Table I, Appendix (B) are average coil velocities corrected to muzzle velocity.

8. PROCEDURE:

The propellant was prepared as follows: Hydrazine nitrate was made by adding the stoichiometric quantity of 95% hydrazine solution to dry C.P. ammonium nitrate. The reaction is

$$NH_4NO_3 + N_2H_4(H_2O) \dashrightarrow N_2H_5NO_3 + NH_3(H_2O)$$

The ammonia and water were removed from the hydrazine nitrate at room temperature by a water injector operated 24 hours followed by evacuating for 24 hours by an oil seal type vacuum pump. The dry hydrazine nitrate was then dissolved in a sufficient quantity of 95% hydrazine to give a mixture of the following composition:

Hydrazine (N_2H_4)	57.0%
Hydrazine Nitrate ($N_2H_5NO_3$)	40.0%
Water (H_2O)	3.0%

Individual charges were prepared from this standard mixture by the addition of 95% hydrazine and water to give the desired hydrazine nitrate and water content.

In general, a round was assembled as follows:

The projectile was crimped in the case; the case volume adjusted by the addition of wax; the projectile magnetized; the propellant added; and the primer inserted. The propellant and primer were assembled at the gun just prior to loading the round in the gun.

The general plan of the tests was to determine the effects of the various parameters, as case assembly, ignition, free volume, and propellant composition and weight on the operation of the liquid propellant system and to manipulate these parameters toward a performance comparable to that obtained with a solid propellant round. In the absence of a knowledge of the specific effects of any of the parameters over a wide range of conditions, it was expedient to investigate each in turn over comparatively narrow limits. Specifically, five variations of case assembly and three experimental primer tube designs, two standard tubes and three standard primer stocks were tested. Free volumes from 69% to 1% were investigated at different charge weights and compositions. Charge weights from 150 to 325 grams, with mass ratios from 0.167 to 0.360 respectively, were utilized with the hydrazine nitrate content varying from 11.7% to 22.6% and water content from 4.5% to 10%.

9. RESULTS AND DISCUSSIONS:

The following information and data are included in the appendices:

Figures 1, 2 and 3 of Appendix (A) are respectively sketches of pressure gage locations in the gun, case assemblies and types of primer extension tubes. Table I of Appendix (B) is a tabulation of data on the firings. This table contains, for each round, weight and composition of propellant, type and performance of primer, case assembly, free volume percentage, muzzle velocity, and pressures at maximum and at ejection. Reproductions of pressure-time oscillograms for more than 90 rounds are included as Figures 4 through 24 of Appendix (C). These are in numerical order by round number. Figures 25 through 30 and Tables II and III of Appendix (D) are summaries of data in tabular and graphical forms. In the discussion which follows, reference to rounds by numbers will in general involve data presented in Table I of Appendix (B) and/or the oscillograms of Figures 4 - 24 of Appendix (C).

a. Case Assembly

Four different case assemblies have been used in these tests. The chamber geometry produced by each of these assemblies is shown in Figure 2 Appendix (A). The first assembly, C-1, consisted of a standard brass case divided into two sections by means of a thin brass diaphragm. This was similar to assemblies described in references (c) and (d). The liquid propellant was charged into either the forward or rear compartment. Extremely high pressures were obtained on rounds with case assemblies C-1-a and C-1-b. On round 2 with case assembly C-1-a, the pressure was estimated in excess of 100,000 psi; and on rounds 3 and 4 with assembly C-1-b, pressures estimated at 90,000, and 80,000 psi respectively were obtained. The propellant weight and composition and primer type for these rounds are given in Table I Appendix (B). While the propellant occupied 90% of the volume of the forward or rear section of the case in these rounds, only about 53% of the total case volume was occupied in round 2 and only about 41% in rounds 3 and 4.

It was assumed that the high pressures obtained with the C-1 case assemblies were largely the result of the high free volumes of these assemblies. To test this assumption, assembly C-2 was prepared. In this assembly, Figure 2 Appendix (A), the chamber volume was reduced by the cork so that the propellant occupied 90% of the remaining volume. Using this assembly on round 5, a maximum pressure of less than 50,000 psi was obtained with the same charge that produced a pressure in excess of 80,000 psi on round 4 with a C-1 case assembly.

While the cork used in assembly C-2 effectively reduced case free volume, the expulsion of the cork with the projectile was objectionable. To correct this objection, case assembly C-3 was developed. The excess case volume in this assembly was occupied by a 50-50 mixture of paraffin and beeswax distributed in the case as shown in Figure 2 of Appendix (A). On rounds 13, 14, 16 and 17 utilizing this assembly, velocities of approximately 2000 f/s were obtained. On similar rounds using the C-2 assembly (rounds 9, 11 and 12) the velocities were around 1800 f/s. In addition to reducing the filler material ejected with the projectile, the C-3 assembly was more adaptable to manipulations of case volume and charge weights without disturbing other parameters.

The C-3 assembly was satisfactory for charge weights below 275 grams and free volumes of 10% and greater. This assembly was used in rounds 13 through 96 of these tests. As the charge weight exceeded 275 grams and at free volumes less than 10%, excessive amounts of wax were lost from the cases on firing. This suggested the desirability of placing as much as possible of the filler in the bottom of the case and resulted in case assembly C-4 shown in Figure 2 Appendix (A). The amount of wax which could be located in the base of the case was limited by the length of the extension tube of the primer. This relocation of the filler reduced the wax losses at the higher charges and lower free volumes.

While the C-4 assembly was, in general, satisfactory for test firings of single hand-loaded rounds, the wax would probably be loosened from the case wall in automatic loading of rounds. For rapid fire tests with automatic loading, a material having greater adherence to the case wall seems desirable.

b. Free Volume

Results reported by reference (d), in which 95% hydrazine was used as the propellant in a 60 caliber gun, indicated an unusual effect obtained with this propellant as compared to solid propellant ammunition. The peak chamber pressure increased as both the charge weight and loading density were decreased. Similar results obtained here are shown by rounds 16 through 23. In the series of rounds, 16 through 23, the peak pressure increased by about 4 times as the space in the case unoccupied by propellant was increased from 10% to near 50% of the total case volume available to the propellant. This case volume, available to but unoccupied by the propellant, is here designated the "free volume", and the ratio, expressed as a per cent, of this unoccupied chamber volume to the total case volume available to the propellant is the "per cent free volume". The free volume ratio is thus comparable to the reciprocal of the loading density as applied in solid propellant ballistics. Low loading densities correspond to high free volume. The use of the free volume concept instead of loading density in liquid propellant work seems preferable since loading densities greater than one are possible because the apparent and real densities of liquid propellants are the same. The dependence of maximum pressure on free volume as obtained on these tests is shown graphically in Figure 25 Appendix (D).

At the lower free volume ratios on these tests, the ballistic system was characterized by relatively low maximum chamber pressure and low rates of pressure rise. This is illustrated by the pressure curves of rounds 12, 13, 14, 34 and 36. The propellant burning apparently extends throughout the projectile travel time in the gun with a large fraction of the propellant decomposing only a short time before ejection of the projectile in many cases. The secondary peaks in the pressure cycle on rounds such as 36, 114, 119, 120 and 125 indicate this latter.

The secondary peaks tended to become more pronounced and to reach a value nearer first maximum as the hydrazine nitrate composition and total charge weight was increased. This is shown by rounds 112 through 125. Secondary peaks were not observed at free volume ratios above 30%. On rounds such as 23, 30 and 32 it would seem that all the propellant is burned during the very short time of the initial pressure rise and that the pressure curve after peak pressure is that of the adiabatic expansion of the gases. Here the system is operating at high ballistic efficiency.

It was also observed that as the free volume increased, the amplitude of the high frequency oscillations on the pressure curves increased.

As the free volume was increased, ignition time (from close of firing key to initial pressure rise) increased. Ignition times vs per cent free volume are shown for representative rounds in Figure 28, Appendix (D). The long ignition times and frequent misfires occurring at high free volume values are probably the result of the primer venting partially or almost completely into the free volume above the propellant. All rounds on these tests were fired at elevations slightly above 0°.

No correlation was observed between free volume and velocity, as will be seen in the free volume-velocity plots of Figures 26 and 27 of Appendix (D).

c. Ignition:

The types of primer stocks and extension tubes, and the charge of the tube are tabulated for each round in Table I, Appendix (B). The design of the extension tubes are shown in Figure 3, Appendix (A). Table I, Appendix (A), and Figure 28 and Table III, Appendix (D) contain ignition delay data. The Mk 21 primer stock is a standard 40mm stock and the Mk 14 and Mk 41 are 3"/50 stocks. Results obtained with the Mk 21 stock were equal to that with the Mk 41 stock. Since this stock required no modification to the standard case, it was used throughout most of the tests.

The first primer tube used, the ET-1, was modeled after the type described in reference (d) and was used with the Mk 21 and Mk 41 stocks. Satisfactory ignition was obtained with this tube when charged with 20 grains of black powder (FFG) and 0.20 grams of ammonium perchlorate.

On rounds 2 and 3, the Mk 14 stock and tube were used. While the excessive pressures obtained on these rounds were attributed primarily to the large free volume, it was thought that the comparatively high energy release of this primer probably contributed to the result by initiating a rapid burning rate or by igniting a large burning surface in the propellant.

The use of the Mk 21 stock and tube on 10 rounds (37 and 40-48) resulted in seven misfires and long ignition delays on two of the three rounds which were ignited. The use of the Mk 41 primer stock without its extension tube also resulted in a misfire (Round 6).

The cost and time involved in fabricating the ET-1 extension tube and the fact that the tube vented irregularly through one to four of the longitudinal grooves dictated the development of a cheaper and more uniformly performing tube. The ET-1 tube was first modified to vent through the end of the tube instead of through the longitudinal grooves. Satisfactory ignition was obtained on three rounds fired with the modified tube, designated ET-2 in Figure 3, Appendix (A). The design was then further simplified to the ET-3 type shown in Figure 3, Appendix (A). This extension tube with three different blowout disc thickness performed satisfactorily on four rounds (58 through 61). From these rounds, an optimum disc thickness of 0.022 was determined. This tube performed satisfactorily on approximately 80 rounds. The diaphragm thickness is the only critical dimension of the tube; rupture of the disc at too low pressure results in very long ignition delays or misfires. There is apparently a critical pressure below which ignition does not occur. The cost of fabricating this type of tube is a small fraction of that of the ET-1 type.

The relation between free volume and ignition is discussed under the section on "Free Volume".

d. Charge Weight and Propellant Composition:

The relations between muzzle velocity and charge weight (or mass ratio) for different propellant compositions are shown in Figures 29 and 30 of Appendix (D). While, in general, velocity increases with increase in charge weight, there is some evidence from these plots that a charge weight is reached above which no increase in velocity is obtained and that a velocity drop will result if the charge is increased further. The charge weight at which this occurs would seem to be a function of hydrazine nitrate and water content and free volume ratio.

The results of increasing the hydrazine nitrate composition of the propellant were to increase maximum chamber pressure, muzzle velocity and the burning rate of the propellant. As the hydrazine nitrate was increased, it is also to be noted that the tendency increased for secondary peak pressures to occur and for the relative amplitude of these to approach that of the first pressure peak. At hydrazine nitrate concentrations of around 12%, round 36, with a charge weight of 350 grams, was the only one which produced a secondary peak. As the percentage was increased to 15, 18 and 22.6%, secondary peaks appeared more frequently and more closely approximated the amplitudes of the first pressure peaks.

The water content of the propellant used in these tests varied from 4.3% to 10% with the majority of rounds at approximately 6.0% and 10%. Increasing the water content increased the ignition time, decreased the burning rate and velocity and produced smoother pressure curves. The benefits of this latter effect was, however, more than offset by the adverse effect on the ignition time and rate of burning.

e. The 40mm Round

A muzzle velocity of the order of 3000 f/s was obtained with 310 - 325 grams of 22.6% hydrazine nitrate, 72.9% hydrazine and 4.3% water at 1% free volume. This exceeds by 150 f/s the velocity obtained with the standard solid propellant round in this barrel. The mean velocity on 10 rounds (125 - 134) with a charge of 325 grams was 3008 f/s with a standard deviation of 61 f/s or 2%. For 9 rounds (135 - 143) with a charge of 310 grams the mean velocity was 2968 f/s with a standard deviation of 71.5 f/s or 2.4%. The combined unbiased standard deviation for the 19 rounds was 70.1 f/s or 2.3%.

The maximum case pressures for these rounds was of the order of 18.8 tsi copper and comparable to that obtained with the standard solid propellant round for the gun.

On the basis of these tests, service velocity of the 40mm gun can be exceeded by 150 f/s with no increase in chamber pressure by the use of monopropellant hydrazine. This was accomplished with only two modifications to existing ammunition components: (1) reduction of the case volume by the addition of a filler, and (2) the use of a special primer stock of simple design. The velocity uniformity obtained on these tests was well below solid propellant performance, but is considered good for the present state of development of liquid propellants in guns.

f. Liquid Propellant Charges for Other Navy Guns:

The approximate hydrazine service charges were calculated for several Navy guns and are presented in Table II of Appendix (D). The basis of these calculations were the results from the 20mm gun presented in reference (d) and from the 40mm obtained at the Naval Proving Ground. Assuming a propellant composition having a density near 1.1, the free volume for the charge and the charge for 10% free volume were calculated. Only in the 20mm gun would the charge produce a free volume near 10%; for all other guns for which calculations were made the free volume would be of the order of 35 to 40%. If a 10% free volume is concluded to be the maximum required or desired, it appears that the chamber volumes of most Navy guns in use today are 25 - 30% larger than required, or desired, for liquid propellant ammunition.

PART D

CONCLUSIONS

10. The following conclusions are made from the results obtained on these tests:

a. The service velocity of the 40mm gun can be exceeded by as much as 150 f/s by the use of the monopropellant hydrazine without exceeding the chamber pressure of the solid propellant service charge.

b. The performance of such a liquid propellant round is of sufficient uniformity to be used in studies of gun erosion.

c. Only two modifications to standard 40mm ammunition components are required for the round developed in these tests. The case volume must be reduced and a special type of primer extension tube used.

d. The wax used in these tests to reduce the case volume is not a completely satisfactory filler. A material which adheres more firmly to the case wall will be required for automatic loading of the round. Erosion studies under rapid fire conditions are dependent on a satisfactory solution to this problem.

e. The prospects of obtaining a uniformity of performance for the monopropellant hydrazine comparable to that obtained with solid propellants are encouraging.

f. Based on the charge determined for the 40mm gun on these tests and the available data from other sources, the chamber volumes of most Navy guns appear to be 25 to 35% larger than required for liquid propellant ammunition.

g. Ignition of the propellant is affected by primer configuration and charge, propellant composition and free volume in the case.

h. Increasing the free volume in the case results in delayed ignition, increased burning rate and higher peak pressure.

i. An increase in the hydrazine nitrate content of the propellant is accompanied by an increase in burning rate, chamber pressure and muzzle velocity, and the production of secondary pressure peaks.

j. An increase in water content of the propellant is accompanied by an increase in ignition time, decrease in burning rate and velocity, and a smoothing of the pressure curve.

- -

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CONFIDENTIAL

NPG REPORT NO. 1200

U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

First Partial Report

on

Liquid Propellants For Guns

- -

First Partial Report

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Liquid Propellant Guns

X

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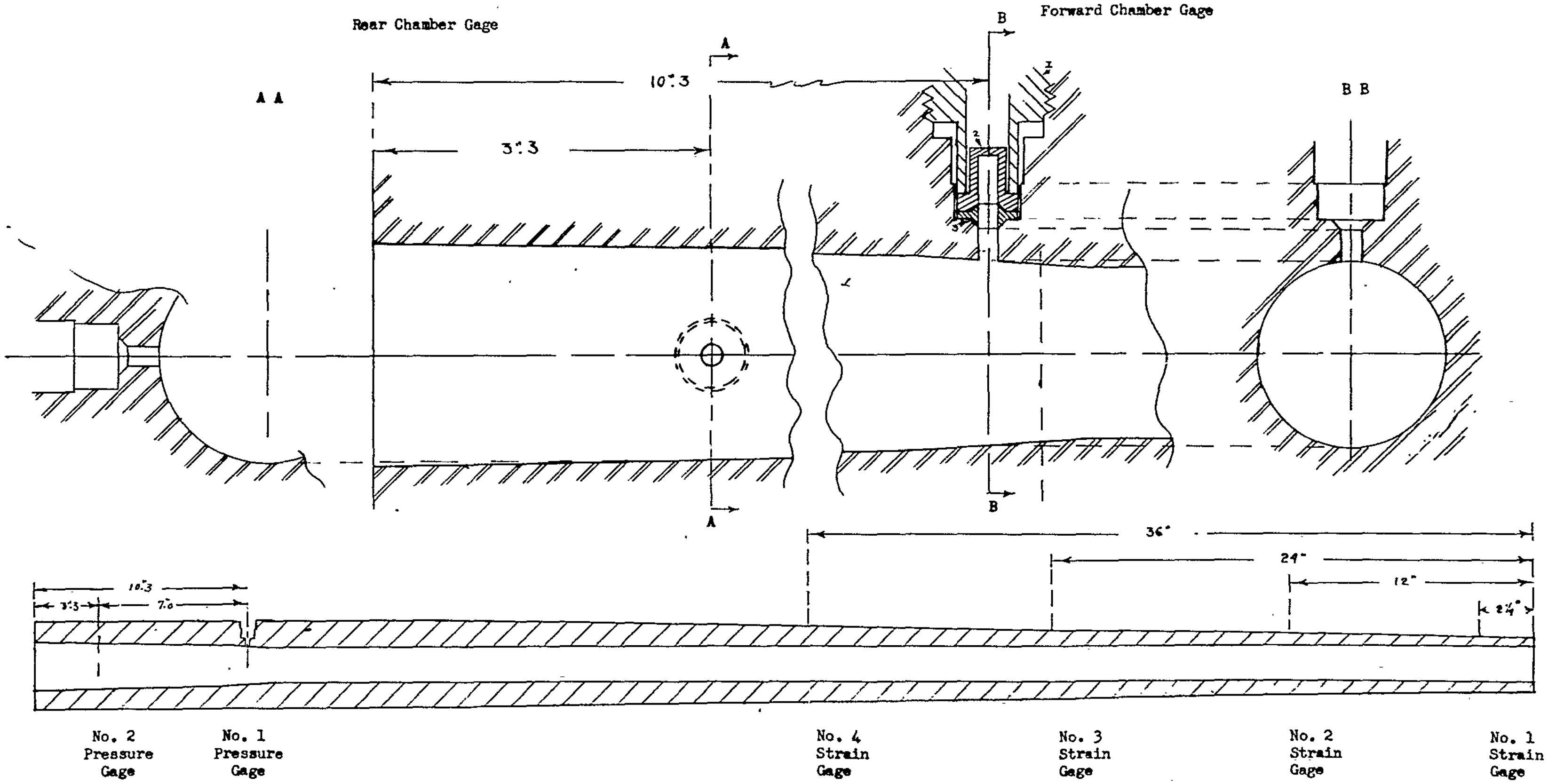
SECURITY INFORMATION

NP9-62827

U.S NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
LIQUID PROPELLANT SECTION

CONFIDENTIAL
(SECURITY INFORMATION)

GAGE LOCATIONS ON GUN SYSTEM



Pressure Gages: Expanding tube type
1: Gage Hold Down Plug
2: Pressure Gage
3: Seal

App. A

Strain Gages: Patch Type
Cemented on
outside wall
of barrel

Figure 1

CONFIDENTIAL

NP9-62828

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

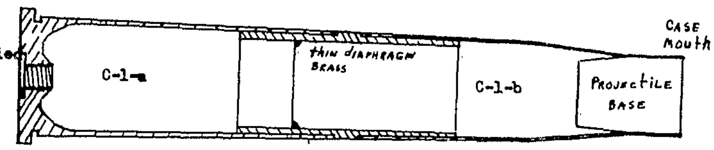
CONFIDENTIAL

Liquid Propellants Section

SKETCH OF 40 MM CASE ASSEMBLIES

C-1

Mk. 2 Case
Primer Hole Modified
to accept Mk. 41
primer stock

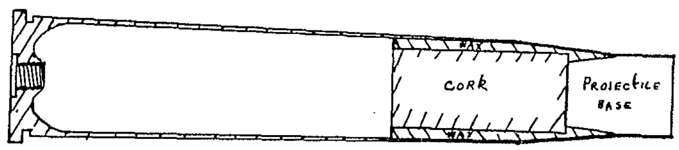


C-1-a: Propellant held in rear portion of case

C-1-b: Propellant held in forward portion of case

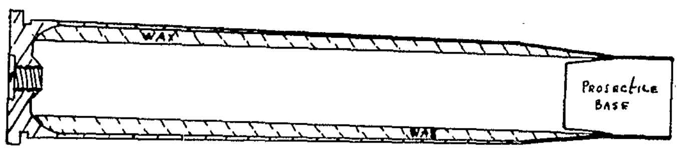
C-2

Mk. 1 Case
Mk. 21 primer
stock



C-3

Mk. 1 Case
Mk. 21 primer
stock



C-4

Mk. 1 Case
Mk. 21 primer
stock

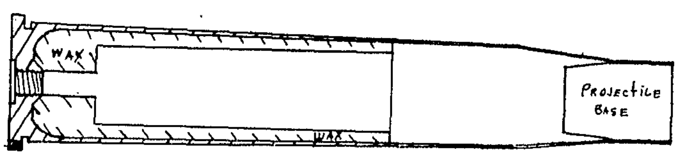


Figure 2

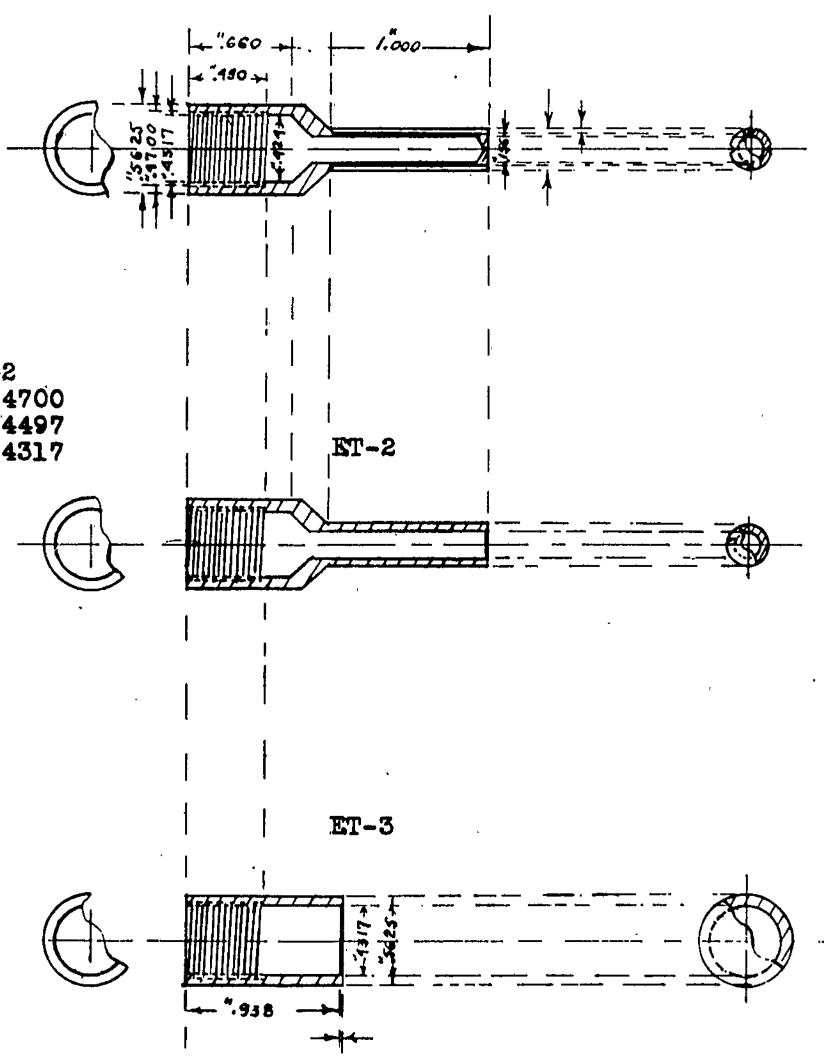
NP9-62829 CONFIDENTIAL

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

SKETCH OF EXTENSION TUBES

ET-1



.470-36NS-2
Maj.Dia.-".4700
Pit.Dia.-".4497
Min.Dia.-".4317

Figure 3

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

TABLE I

Round No.	Propellant Charge Weight Grams	% $N_2H_5NO_3$	% N_2H_4	% H_2O	*Mass Ratio	Primer Stock	Extension Tube Type	**FPG Grains	NH_4ClO_4 Grams	Venting	Case Chamber Assembly	Free Volume %	Recoil Inches	Velocity f/s	Case Pressure: Peak Pressure 3103 Gage	Peak Pressure 10103 Gage	Ejection Pressure 3103 Gage	Ejection Pressure 10103 Gage	Ignition Delay Millisec.	Eject. Time Millisec.	P-T Record Quality	Comments
1	250	12.4	81.3	6.3	.278	Mk. 41	ET-1	-	.20	1 groove	C-1-a	47.0	-	-	-	-	-	-	-	-	-	Misfire
2	"	"	"	"	"	Mk. 14	Standard Mk. 14 assembly				"	"	3.3	2805	P 100,000 lbs.		Destroyed both gages		1.3	-	P	Damaged Breech Block
3	200	"	"	"	.222	"	"	"	"		C-1-b	59.0	2.8	2403	P 90,000 lbs.		"	"	1.7	2.7	P	" " "
4	"	"	"	"	"	Mk. 41	ET-1	10	.20	4 grooves	"	"	3.0	2442	P 80,000 lbs.		"	"	2.1	"	P	
5	"	"	"	"	"	"	"	"	"	3 grooves	C-2	10.0	2.9	2480	-	47,600	-	-	3.18	4.7	P	
6	"	"	"	"	"	"	None	-	-	-	"	"	-	-	-	-	-	-	-	-	-	Misfire
7	"	"	"	"	"	"	ET-1	7	-	3 grooves	"	"	-	-	-	-	-	-	-	-	-	"
8	"	"	"	"	"	"	"	"	.20	3 "	"	"	-	-	-	-	-	-	-	-	-	"
9	"	12.0	78.0	10.0	"	"	"	10	"	4 grooves	"	"	3.3	1928	21,600	20,500	4,865	3,432	4.32	10.3	G	
10	"	"	"	"	"	Mk. 21	"	12	"	Failed	"	"	-	-	-	-	-	-	-	-	-	Misfire
11	"	"	"	"	"	Mk. 41	"	10	"	2 grooves	"	"	2.8	1669	17,850	25,850	6,850	4,200	3.5	10.4	G	
12	"	"	"	"	"	Mk. 21	"	20	"	3 "	"	"	2.5	1755	12,900	14,150	4,600	5,400	3.2	11.3	G	
13	"	"	"	"	"	Mk. 41	"	10	"	2 "	C-3	"	2.8	1821	13,200	13,800	5,250	7,400	2.8	10.2	G	
14	"	"	"	"	"	"	"	"	"	3 "	"	"	"	2042	15,850	15,700	7,600	7,000	3.9	10.8	G	
15	"	"	"	"	"	Mk. 21	ET-2	20	"		"	"	-	-	-	-	-	-	-	-	-	Misfire
16	"	11.9	78.1	"	"	"	ET-1	"	"	2 grooves	"	"	2.8	2106	27,500	25,250	5,850	6,200	1.9	10.8	G	About 30 gms of wax lost
17	"	"	"	"	"	"	"	"	"	1 groove	"	"	"	2005	17,900	17,350	7,550	9,300	2.4	9.2	G	" " " " " "
18	"	"	"	"	"	"	"	"	"	3 grooves	"	16.5	"	1903	17,350	16,700	6,250	6,950	1.8	8.8	G	" " " " " "
19	"	"	"	"	"	"	"	"	"	3 "	"	25.1	"	1929	20,600	21,800	10,100	10,200	2.9	9.0	F	" " " " " "
20	"	"	"	"	"	"	"	"	"	2 "	"	30.9	"	2003	23,700	Unreadable	12,200	unreadable	2.3	7.8	P	" " " " " "
21	"	"	"	"	"	"	"	"	"	4 "	"	35.2	"	1342	-	-	-	-	1.9	8.2	P	About 50 gms of wax lost
22	"	"	"	"	"	"	"	"	"	3 "	"	45.2	"	1957	27,550	25,750	11,750	4,100	3.4	9.0	P	" 30 " " " "
23	"	"	"	"	"	"	"	"	"	4 "	"	49.4	2.9	2650	77,200	61,000	9,500	6,450	2.7	6.4	P	" " " " " "
24	"	"	"	"	"	"	"	"	-	3 "	"	45.1	2.8	2003	35,200	32,200	3,200	4,400	4.9	9.9	P	
25	"	"	"	"	"	"	ET-2	"	-	.007" thick	"	"	-	-	-	-	-	-	-	-	-	Misfire
26	150	"	"	"	.167	"	ET-1	"	.20	3 grooves	"	50.0	2.7	2047	35,900	36,300	3,700	4,400	4.9	9.9	G	
27	"	"	"	"	"	"	"	"	"	3 "	"	45.0	"	1744	28,350	20,850	4,300	3,900	2.9	8.2	G	
28	"	"	"	"	"	"	"	"	"	4 "	"	50.0	"	1741	28,200	27,700	5,200	6,600	3.8	9.1	P	
29	"	"	"	"	"	"	"	"	"	3 "	"	55.0	"	2023	29,400	29,600	4,050	1,600	4.9	10.5	G	
30	"	"	"	"	"	"	"	"	"	3 "	"	60.0	"	2093	40,550	34,100	4,600	5,450	6.8	10.6	P	
31	"	"	"	"	"	"	"	"	"	-	"	65.0	-	-	-	-	-	-	-	-	-	Misfire
32	"	"	"	"	"	"	"	"	"	4 grooves	"	69.0	2.7	1978	P-T Record Unreadable				9.4	14.25	P	
33	"	"	"	"	"	"	"	"	"	3 "	"	35.0	2.5	1794	15,100	20,600	3,600	5,900	1.37	8.8	G	
34	250	"	"	"	.278	"	"	"	"	2 "	"	10.0	2.9	2086	19,950	22,600	8,150	11,300	1.0	8.5	G	Tube annealed at 1000°F for 1 hr. and air cooled
35	300	"	"	"	.333	"	"	"	"	2 "	"	"	3.0	2194	18,050	19,000	15,050	18,500	2.0	9.0	G	" " "
36	350	"	"	"	.389	"	"	"	"	4 "	"	"	"	2059	19,050	23,000	13,850	15,350	1.9	5.7	F	
37	150	"	"	"	.167	"	Standard extension tube				"	"	-	-	-	-	-	-	-	-	-	Misfire
38	"	"	"	"	"	"	ET-3	20	.20	.008" thick	"	"	-	-	-	-	-	-	-	-	-	Tube end .008", misfire
39	200	"	"	"	.222	"	ET-1	"	"	2 grooves	"	35.0	2.7	1978	21,550	21,650	5,150	5,500	3.8	14.4	G	New P-T gages
40	150	"	"	"	.167	"	Standard extension tube			-	"	25.0	2.3	1566	23,200	21,150	4,050	4,400	6.7	15.8	G	
41	"	"	"	"	"	"	"	"	"	-	"	"	-	-	-	-	-	-	-	-	-	Misfire
42	"	"	"	"	"	"	"	"	"	-	"	10.0	-	-	-	-	-	-	-	-	-	"
43	"	"	"	"	"	"	"	"	"	-	"	20.0	2.7	1667	Missed P-T Record						-	
44	"	"	"	"	"	"	"	"	"	-	"	30.0	-	-	-	-	-	-	-	-	-	Misfire
45	"	"	"	"	"	"	"	"	"	-	"	40.0	-	-	-	-	-	-	-	-	-	"
46	"	"	"	"	"	"	"	"	"	-	"	20.0	2.7	1873	20,800	23,600	3,800	4,250	4.6	19.1	G	
47	"	"	"	"	"	"	"	"	"	-	"	69.0	-	-	-	-	-	-	-	-	-	Misfire
48	"	12.6	81.4	6.0	"	"	"	"	"		"	20.0	-	-	-	-	-	-	-	-	-	"
49	"	11.9	78.1	10.0	"	"	ET-1	20	.20	1 groove	"	35.0	2.7	1813	16,250	20,150	4,250	4,400	3.7	13.9	G	
50	200	"	"	"	.278	"	"	"	"	1 "	"	40.0	-	-	-	-	-	-	-	-	-	Misfire
51	"	"	"	"	"	"	"	"	"	3 grooves	"	50.0	-	-	-	-	-	-	-	-	-	Misfire, tube annealed for 1 hr at 1000°F, water quench
52	150	"	"	"	.167	"	"	"	"	3 "	"	10.0	2.3	1507	-	17,200	-	8,150	1.9	9.5	G	
53	"	12.6	81.4	6.0	"	"	ET-2	"	"	.006" thick	"	17.0	2.6	1880	59,900	48,900	3,900	5,050	2.0	6.9	P	
54	"	"	"	"	"	"	"	"	"	.003" "	"	20.0	-	-	-	-	-	-	-	-	-	Misfire
55	"	"	"	"	"	"	ET-1	"	"	3 grooves	"	"	2.7	1843	34,700	30,100	8,400	5,550	2.1	8.7	G	
56	"	"	"	"	"	"	"	"	"	3 "	"	"	"	1807	34,000	30,950	10,000	10,900	1.6	6.3	P	
57	"	"	"	"	"	"	ET-2	"	"	.004" thick	"	"	"	2025	46,150	50,540	5,750	7,750	"	6.6	P	
58	"	"	"	"	"	"	ET-3	"	"	.025" "	"	"	"	2017	36,650	30,100	5,350	4,500	1.4	7.5	G	
59	"	"	"	"	"	"	"	"	"	.020" "	"	"	"	2113	36,350	30,900	6,250	6,100	2.62	7.9	G	
60	"	"	"	"	"	"	"	"	"	.015" "	"	"	"	2092	27,000	25,350	4,650	4,550	7.6	13.8	G	
61	"	"	"	"	"	"	"	"	"	"	"	"	"	2190	44,250	39,900	6,000	4,100	6.0	12.9	P	
62	"	"	"	"	"	"	"	"	"	.022" thick	"	10.0	2.8	2076	25,300	28,900	5,550	3,800	3.2	9.2	F	
63	"	"	"	"	"	"	"	"	"	"	"	20.0	"	2127	29,400	32,850	4,700	5,850	2.6	6.9	F	
64	"	"	"	"	"	"	"	"	"	"	"	30.0	-	2017	-	24,500	-	4,600	3.3	8.4	F	
65	"	"	"	"	"	"	"	"	"	"	"	40.0	-	2037	Missed P-T Record				-	-	-	
66	"	"	"	"	"	"	"	"	"	"	"	50.0	-	-	-	-	-	-	-	-	-	Misfire
67	"	"	"	"	"	"	"	"	"	"	"	66.0	-	-	-	-	-	-	-	-	-	"
68	"	"	"	"	"	"	"	"	"	"	"	40.0	2.8	2067	33,050	30,850	6,300	5,700	4.2	9.3	P	
69	200	"	"	"	.222	"	"	"	"	"	"	30.0	3.2	2341	38,900	34,050	8,100	9,100	3.0	7.2	P	
70	225	"	"	"	.250	"	"	"	"	"	"	"	"	2424	49,700	45,600	9,600	12,400	"	6.8	P	
71	250	"	"	"	.278	"	"	"	"	Good	"	"	"	2437	Missed P-T Record				-	-	-	
72	275	"	"	"	.305	"	"	"	"	"	"	"	"	2575	43,100	40,900	13,650	13,900	2.9	6.8	P	
73	300	"	"	"	.333	"	"	"	"	"	"	"	-	-	46,150	40,100	17,300	18,350	"	4.0	P	
74	150	15.0	78.9	6.1	.167	"	"	"	"	"	"	"	-	-	-	-	-	-	-	-	-	Misfire, unseated projectile
75	"	18.0	76.2	5.8	"	"	"	"	"	"	"	"	2.8	2096	45,450	35,950	3,875	5,000	2.6	7.2	P	
76	"	22.6	71.9	5.5	"	"	"	"	"	"	"	"	"	2081	43,850	Broke Gage	5,250	Broke Gage	2.5	6.6	P	
77	"	15.0	78.9	6.1	"	"	"	"	"	"	"	"	2.9	2196	54,800	38,000	15,450	10,950	2.2	6.2	P	
78	"	22.6	71.9	5.5	"	"	"	"	"	"	"	"	-	-	-	-	-	-	-	-	-	Misfire
79	175	18.0	76.2	5.8	.195	"	"	"	"	"	"	"	3.0	2140	35,275	32,050	5,875	8,950	2.9	7.3	P	
80	200	"	"	"	.222	"	"	"	"	"	"	"	"	2266	52,900	-	10,150	9,700	2.5	6.7	P	

CONFIDENTIAL
SECURITY INFORMATION

NP9-42857

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

CONFIDENTIAL

Liquid Propellants Section

TABLE I (Continued)

Round No.	Propellant Charge Weight Grams	Propellant Charge % $N_2H_5NO_3$	Propellant Charge % N_2H_4	Propellant Charge % H_2O	*Mass Ratio	Primer Stock	Extension Tube Type	Extension Tube **FFG Grains	Extension Tube NH_4ClO_4 Grams	Venting	Case Chamber Assembly	Case Free Volume %	Recoil Inches	Velocity f/s	Case Pressure Peak Pressure 3103 Gage	Case Pressure Peak Pressure 10103 Gage	Case Pressure Ejection Pressure 3103 Gage	Case Pressure Ejection Pressure 10103 Gage	Ignition Delay Millisec.	Eject. Time Millisec.	P-T Record Quality	Comments
81	225	18.0	76.2	5.8	.250	Mk. 21	ET-3	20	.20	Good	C-3	30.0	3.0	2403	41,675	29,800	9,075	7,450	2.1	6.1	P	The primer diaphragms
82	250	"	"	"	.278	"	"	"	"	"	"	"	"	2581	57,775	49,325	11,875	12,050	20.5	24.0	P	were checked for
83	275	"	"	"	.305	"	"	"	"	"	"	"	-	-	-	-	-	-	-	-	-	several tubes, and the
84	300	"	"	"	.333	"	"	"	"	"	"	"	-	-	-	-	-	-	-	-	-	thickness varied from
85	275	"	"	"	.305	"	"	"	"	"	"	"	3.2	2572	Record Unreadable				1.5	4.9	P	.006" to .036". The
86	250	"	"	"	.278	"	"	"	"	"	"	"	2.8	2491	Four strain gages located on barrel. See Appen. F					-	-	misfires were attri-
87	275	"	"	"	.305	"	"	"	"	"	"	20.0	2.9	2725	" "	" "	" "	" "	-	-	-	buted to this fact.
88	"	"	"	"	"	"	"	"	"	"	"	10.0	"	2760	60,825	52,050	16,225	18,075	2.6	5.9	F	Diaphragm thickness
89	"	"	"	"	"	"	"	"	"	"	"	"	"	2719	48,100	Only one gage	11,025	Only one gage	2.8	6.4	F	is now checked before
90	"	"	"	"	"	"	"	"	"	"	"	"	"	2660	Only one gage	43,300	Only one gage	17,975	2.4	6.1	F	loading.
91	290	"	"	"	.322	"	"	"	"	"	"	"	3.0	2748	56,200	49,000	14,050	14,550	2.8	6.2	P	
92	300	"	"	"	.333	"	"	"	"	"	"	"	"	2717	38,925	48,425	25,550	16,000	2.2	4.9	P	
93	275	"	"	"	.305	"	"	"	"	"	"	30.0	2.9	2678	36,150	45,375	14,950	18,225	2.7	6.6	P	
94	250	15.0	78.9	6.1	.278	"	"	"	"	"	"	10.0	2.8	2616	24,275	30,875	8,950	8,825	3.7	7.4	F	
95	"	"	"	"	"	"	"	"	"	"	"	20.0	"	2499	33,150	36,000	1,100	11,700	2.9	6.4	P	
96	"	"	"	"	"	"	"	"	"	"	"	30.0	2.9	2681	36,500	44,975	8,525	13,225	2.4	6.3	P	
97	275	18.0	76.2	5.6	.305	"	"	"	"	"	C-4	35.5	"	2802	Both gages ruined		-	-	-	-	-	
98	"	"	"	"	"	"	"	"	"	"	"	37.6	-	-	-	-	-	-	-	-	-	Misfire
99	"	"	"	"	"	"	"	"	"	"	"	25.0	2.9	2529	37,725	49,500	18,900	14,775	4.5	8.2	F	End of case torn off
100	"	"	"	"	"	"	"	"	"	"	"	"	-	-	-	-	-	-	-	-	-	Misfire
101	"	"	"	"	"	"	"	"	"	"	"	"	2.9	2587	46,775	40,725	11,950	14,975	2.4	5.9	P	
102	200	12.0	78.0	10.0	.222	"	"	"	"	"	"	10.0	-	-	-	-	-	-	-	-	-	Misfire
103	"	"	"	"	"	"	ZT-1	"	"	2 grooves	"	"	2.7	1684	20,625	18,500	9,525	8,675	1.7	8.6	G	
104	150	12.6	81.4	6.0	.167	"	"	"	"	"	"	20.0	2.3	1280	25,075	20,800	1,450	1,600	1.6	7.7	F	
105	"	"	"	"	"	"	ZT-3	"	"	Good	"	"	2.7	1719	28,825	27,300	7,200	7,800	2.5	8.1	F	
106	217.7	18.0	76.2	5.8	.241	"	Standard Extension Tube				C-4	"	2.95	2359	46,450	51,750	12,500	13,700	"	6.0	F	
107	"	"	"	"	"	"	"	"	.1	-	"	"	2.85	2415	58,975	45,600	16,850	15,675	3.1	7.6	F	NH_4ClO_4 added to base
108	"	"	"	"	"	"	"	"	"	-	"	18.0	3.1	2297	-	-	-	-	-	-	-	of projectiles for
109	222.9	17.6	74.4	8.0	.247	"	"	"	"	-	"	16.5	2.85	2215	42,825	33,275	5,550	8,325	6.0	22.0	G	rounds 107, 108, 109
110	227.9	17.2	72.8	10.00	.253	"	"	"	"	-	"	15.2	"	2007	33,000	27,550	7,675	7,275	4.0	13.5	G	and 110
111	250	15.0	80.5	4.5	.278	Mk. 21	ET-3	20.0	.20	Good	"	10.0	2.90	2492	51,575	42,425	15,900	15,950	3.1	6.8	F	
112	"	"	"	"	"	"	"	"	"	"	"	5.0	"	2554	29,550	-	14,550	14,525	2.1	6.1	P	
113	"	"	"	"	"	"	"	"	"	"	"	1.0	2.95	2578	27,175	-	10,450	9,400	2.4	6.3	P	
114	"	18.0	76.2	5.8	"	"	"	"	"	"	"	"	"	2666	40,200	35,350	10,725	10,150	4.1	7.8	P	
115	"	15.0	80.5	4.5	"	"	"	"	"	"	"	"	"	2466	36,450	-	13,600	-	2.4	6.5	G	
116	275	"	"	"	.305	"	"	"	"	"	"	"	3.0	2550	39,375	36,325	14,700	14,250	2.7	"	F	
117	300	"	"	"	.333	"	"	"	"	"	"	"	3.1	2494	No pressure-time data		-	-	2.6	6.9	G	Case not aligned in
118	250	18.0	76.2	5.8	.278	"	"	"	"	"	"	.8	2.9	2430	34,400	33,500	12,625	17,000	2.1	6.4	G	chamber
119	275	"	"	"	"	"	"	"	"	"	"	2.6	3.0	2730	36,500	35,050	11,350	12,850	2.6	6.2	F	
120	300	"	"	"	.333	"	"	"	"	"	"	2.2	3.1	2773	41,550	46,400	19,775	17,075	2.9	7.1	F	
121	325	"	"	"	.360	"	"	"	"	"	"	0.8	"	2676	No pressure-time record		-	-	-	-	-	
122	250	22.6	72.9	4.3	.278	"	"	"	"	"	"	"	3.0	2716	35,825	43,450	9,175	9,625	2.0	5.9	F	
123	275	"	"	"	.305	"	"	"	"	"	"	2.6	3.1	2585	-	-	-	-	-	-	-	Leak at forward P-T hole
124	300	"	"	"	.333	"	"	"	"	"	"	2.2	"	2655	51,800	-	19,725	25,250	2.2	5.8	P	" " " " "
125	325	"	"	"	.360	"	"	"	"	"	"	0.8	"	2977	51,125	57,500	12,175	29,000	1.8	5.5	P	
126	"	"	"	"	"	"	"	"	"	"	"	1.0	2.9	3053	No pressure-time data. Copper crusher gage reading 18.4 ton							
127	"	"	"	"	"	"	"	"	"	"	"	"	"	3035	" "	" "	38,764	23,200	3.0	6.1	F	Lost gage
128	"	"	"	"	"	"	"	"	"	"	"	"	"	2882	" "	" "	42,256	5,200	2.1	5.2	F	Lost gage, slight
129	"	"	"	"	"	"	"	"	"	"	"	"	"	3061	" "	" "	Copper crusher gage reading 19.6 ton					blowback
130	"	"	"	"	"	"	"	"	"	"	"	"	"	2913	" "	" "	" "	" "	18.0 "			
131	"	"	"	"	"	"	"	"	"	"	"	"	"	3042	" "	" "	" "	" "	17.5 "			
132	"	"	"	"	"	"	"	"	"	"	"	"	"	3031	" "	" "	" "	" "	17.3 "			
133	"	"	"	"	"	"	"	"	"	"	"	"	"	3009	" "	" "	" "	" "	18.6 "			
134	"	"	"	"	"	"	"	"	"	"	"	"	"	3074	" "	" "	" "	" "	22.5 "			
135	310	"	"	"	.344	"	"	"	"	"	"	"	"	2958	" "	" "	No crusher gages					
136	"	"	"	"	"	"	"	"	"	"	"	"	"	2965	" "	" "	" "	" "				
137	"	"	"	"	"	"	"	"	"	"	"	"	"	3033	" "	" "	" "	" "				
138	"	"	"	"	"	"	"	"	"	"	"	"	"	2945	" "	" "	" "	" "				
139	"	"	"	"	"	"	"	"	"	"	"	"	"	3025	" "	" "	" "	" "				
140	"	"	"	"	"	"	"	"	"	"	"	"	"	2993	" "	" "	" "	" "				
141	"	"	"	"	"	"	"	"	"	"	"	"	"	3050	" "	" "	" "	" "				
142	"	"	"	"	"	"	"	"	"	"	"	"	"	2950	" "	" "	" "	" "				
143	"	"	"	"	"	"	"	"	"	"	"	"	"	2794	" "	" "	" "	" "				

* Mass Ratio: propellant charge weight/projectile weight
** FFG: Black powder granulation grade

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SECURITY INFORMATION

PRESSURE-TIME OSCILLOGRAMS

Gun:	40mm, Mk 1, Barrel No. 14934
Case:	Modified Mk 1 and Mk 2
Primer:	Special Designs
Propellant:	Hydrazine, hydrazine nitrate, water solutions
Trace #1:	Forward chamber pressure gage
Trace #2:	Rear chamber pressure gage
Trace #3:	Projectile ejection time
Trace #4:	Time of close of firing key
Trace #5:	Reference
CFK:	Close of firing key
E:	Ejection time
Timing:	One millisecond marker

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/8/52	11	200 Grams	10.0%	12.0	78.0	10.0
8/11/52	12	" "	"	"	"	"
8/12/52	13	" "	"	"	"	"
8/14/52	14	" "	"	"	"	"

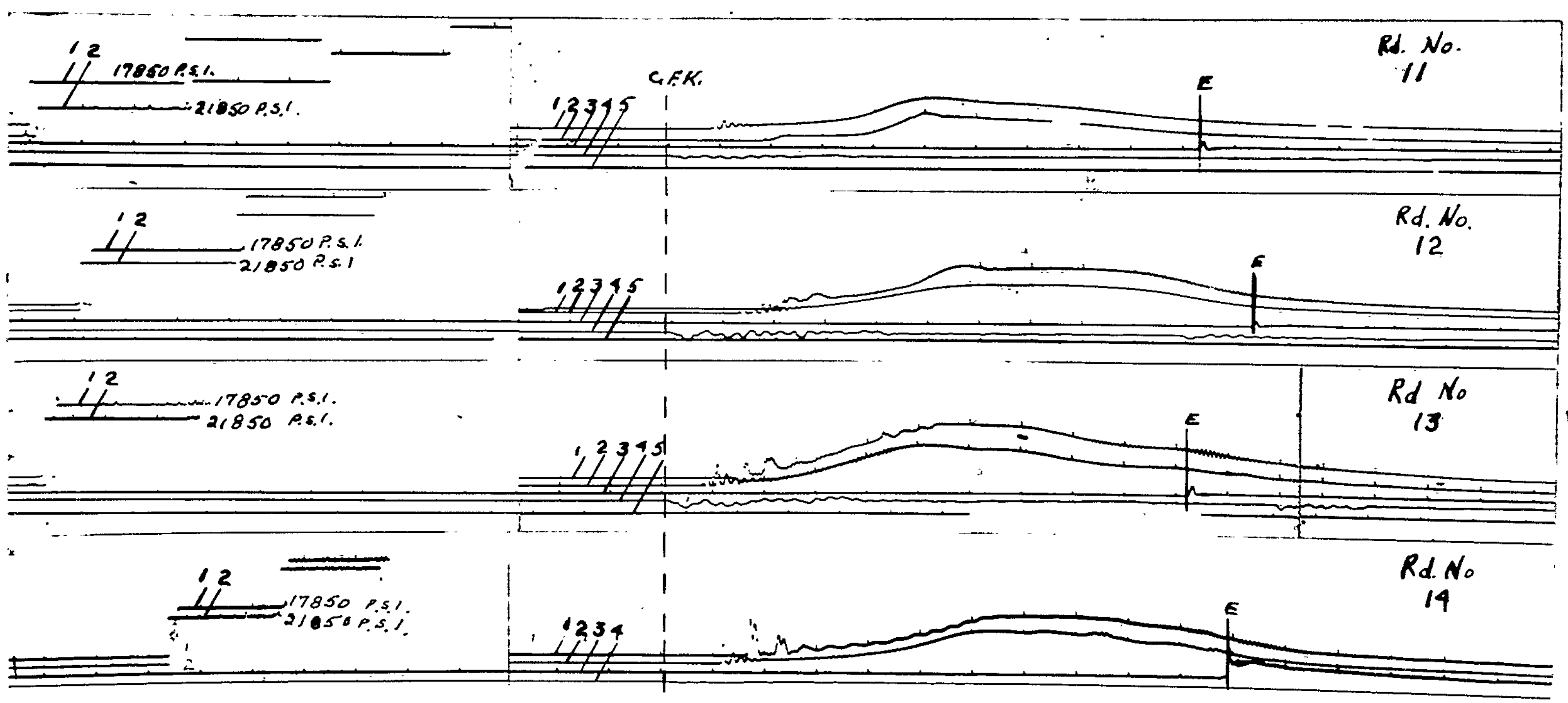

FIGURE 4

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/15/52	16	200 Grams	10.0%	11.9	78.1	10.0
"	17	" "	"	"	"	"
"	18	" "	16.5%	"	"	"
"	19	" "	25.1%	"	"	"

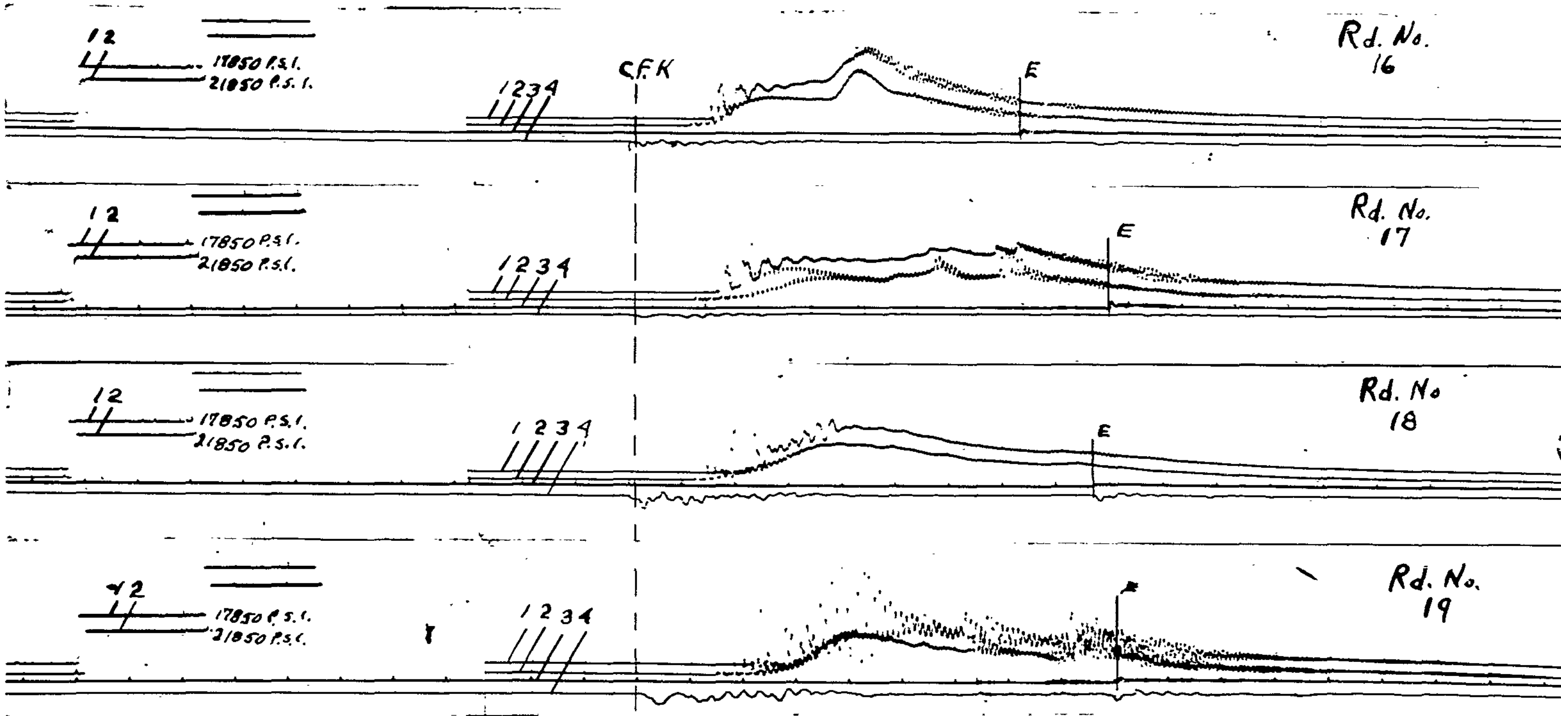


Figure 5

NP9-62835 CONFIDENTIAL

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/15/52	20	200 Grams	30.9%	11.9	78.1	10.0
"	21	" "	35.2%	"	"	"
"	22	" "	45.2%	"	"	"
"	23	" "	49.4%	"	"	"

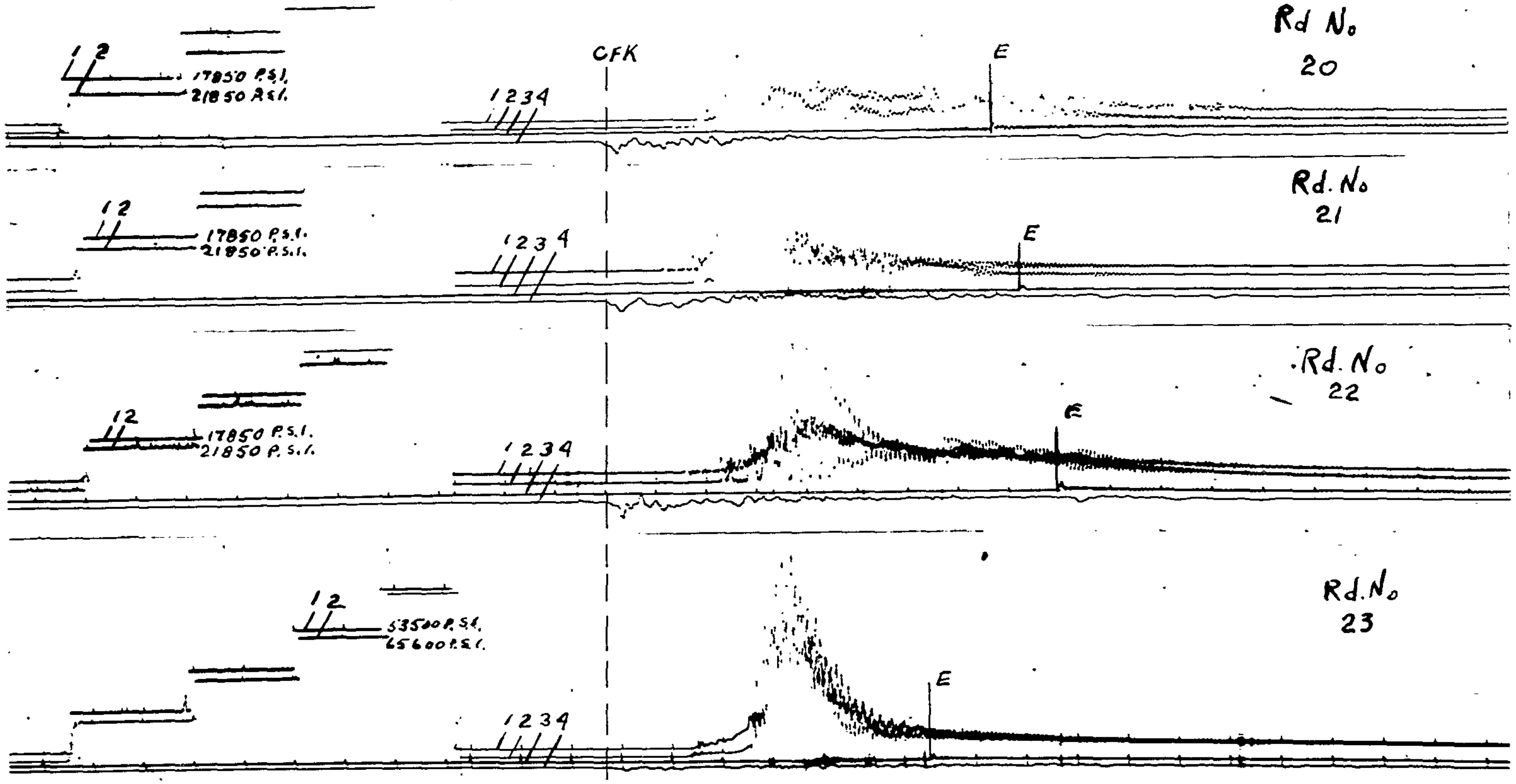


Figure 6

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/20/52	24	200 Grams	45.1%	11.9	78.1	10.0
"	26	150 "	50.0%	"	"	"
8/22/52	27	" "	45.0%	"	"	"
"	28	" "	50.0%	"	"	"

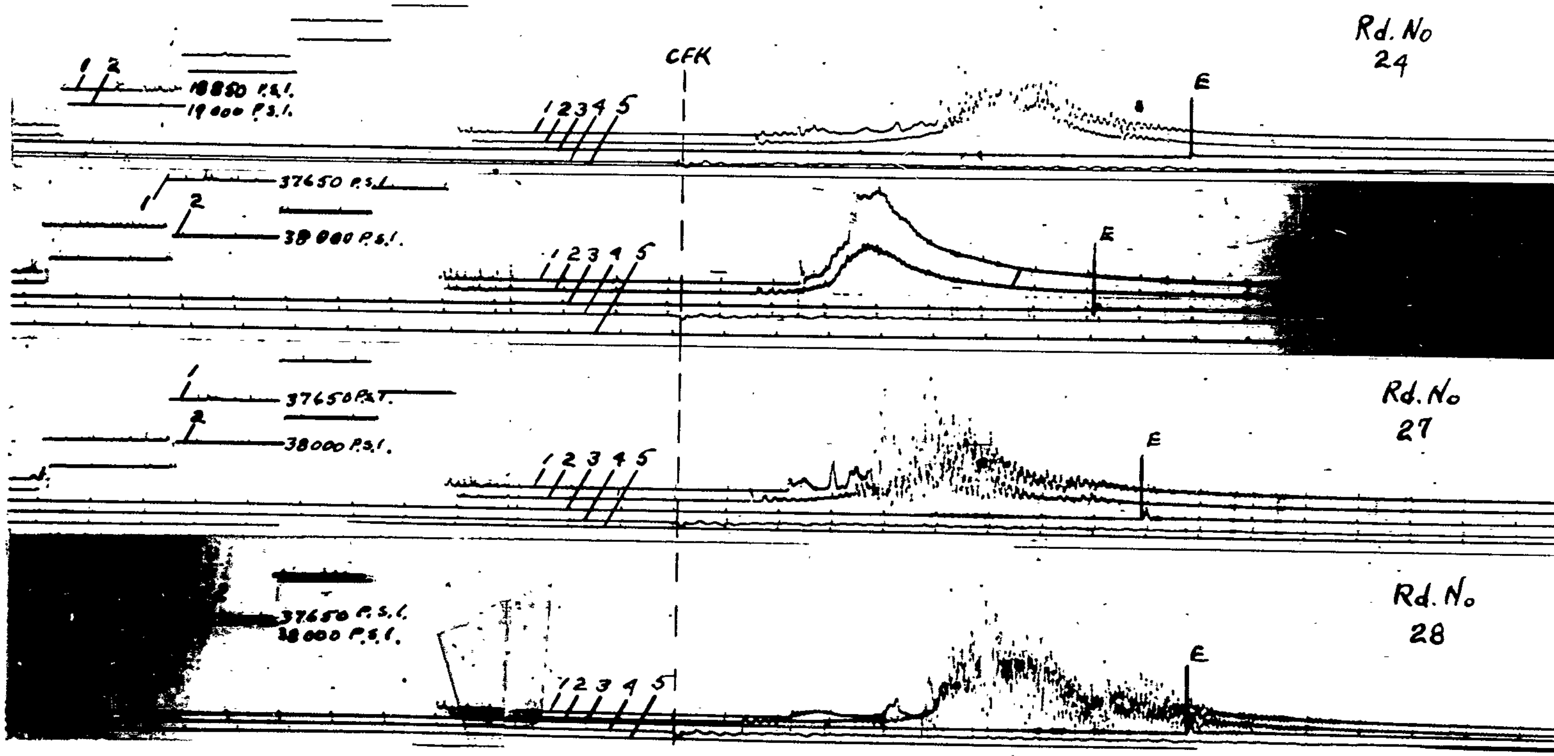


FIGURE 7

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/22/52	29	150 Grams	55.0%	11.9	78.1	10.0
"	30	" "	60.0%	"	"	"
"	32	" "	69.0%	"	"	"
8/26/52	33	" "	35.0%	"	"	"

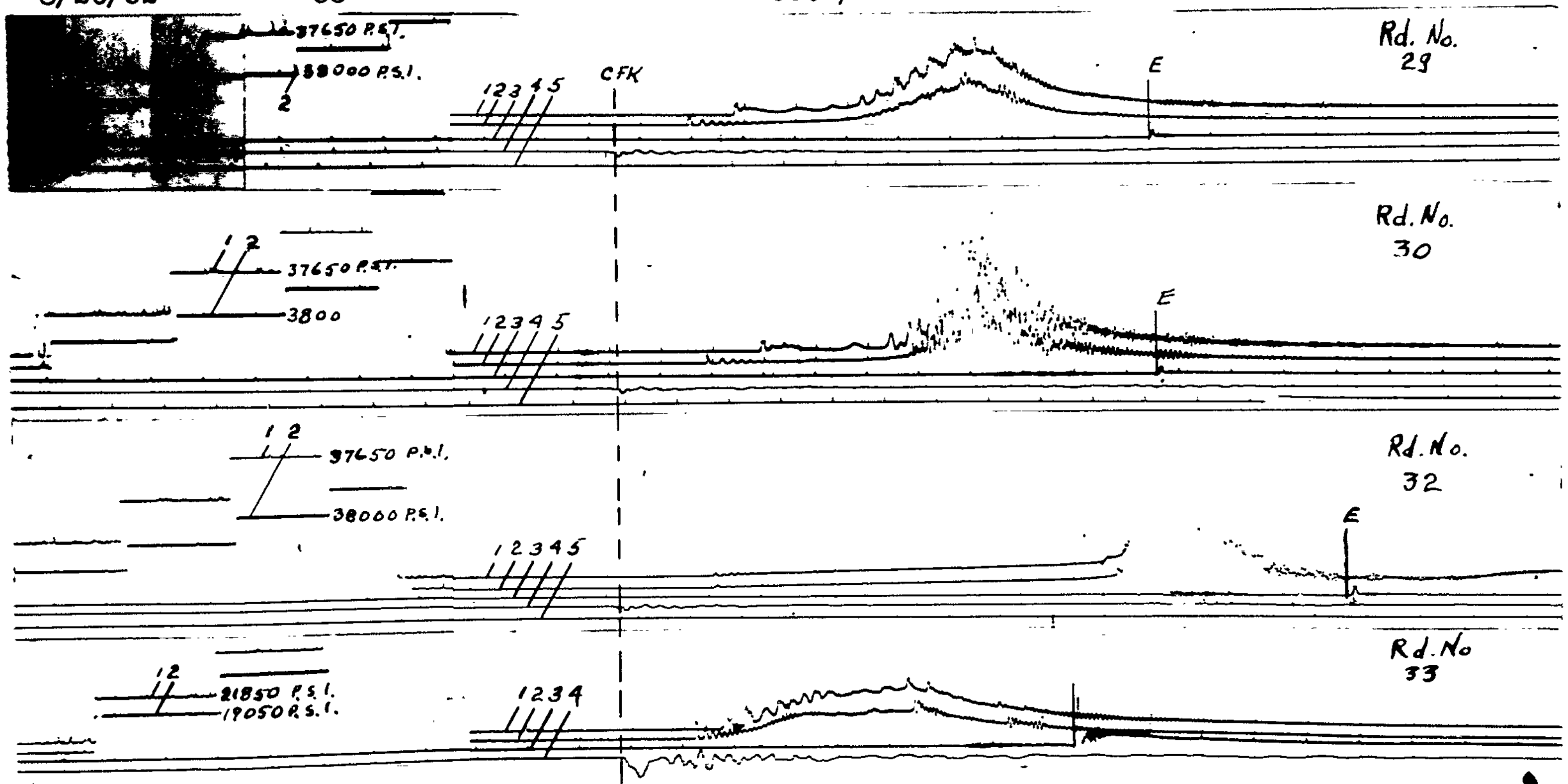


FIGURE 8

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/27/52	34	250 Grams	10.0%	11.9	78.1	10.0
"	35	300 "	"	"	"	"
"	36	350 "	"	"	"	"
9/10/52	39	200 "	"	"	"	"

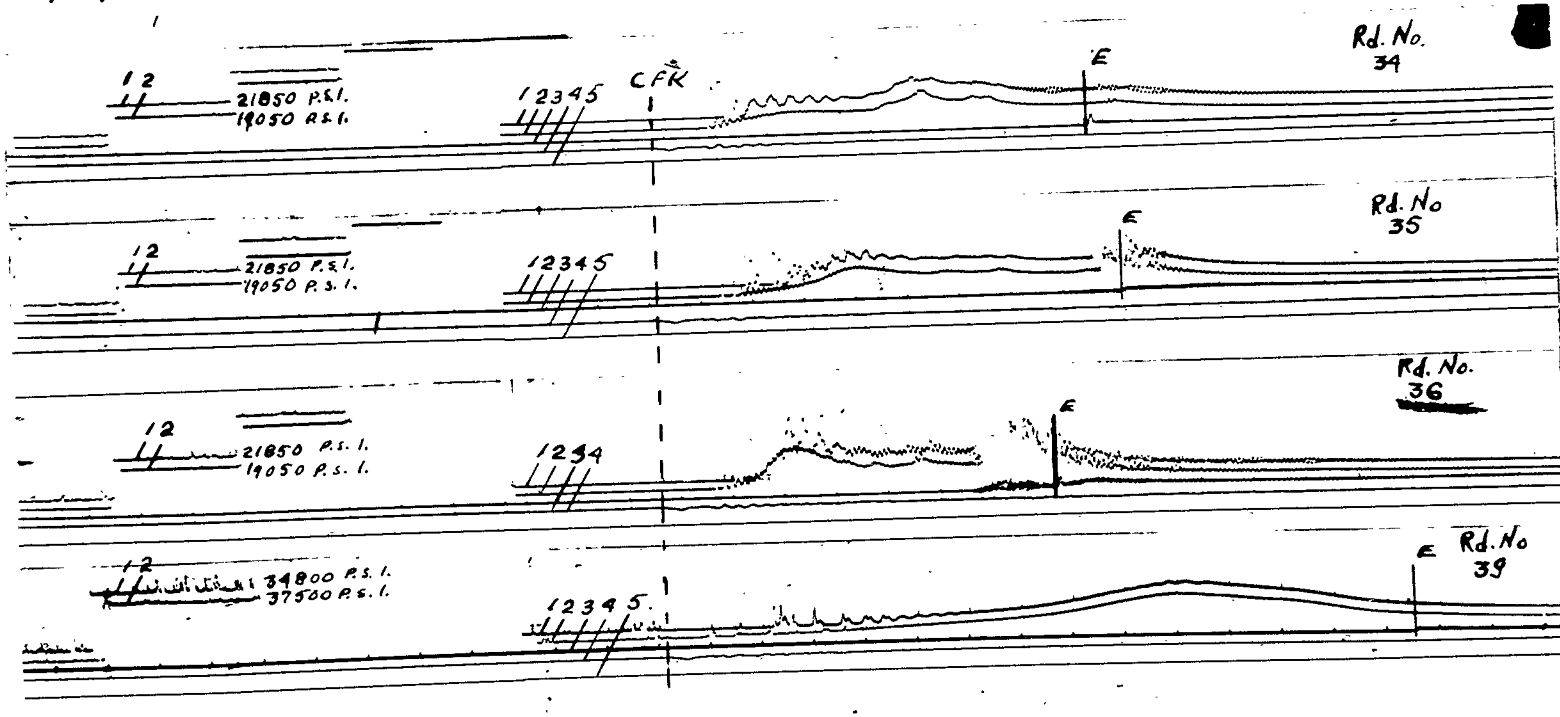


FIGURE 9

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
9/10/52	40	150 Grams	25.0%	11.9	78.1	10.0
"	46	" "	20.0%	"	"	"
"	49	" "	35.0%	"	"	"
"	52	" "	10.0%	"	"	"

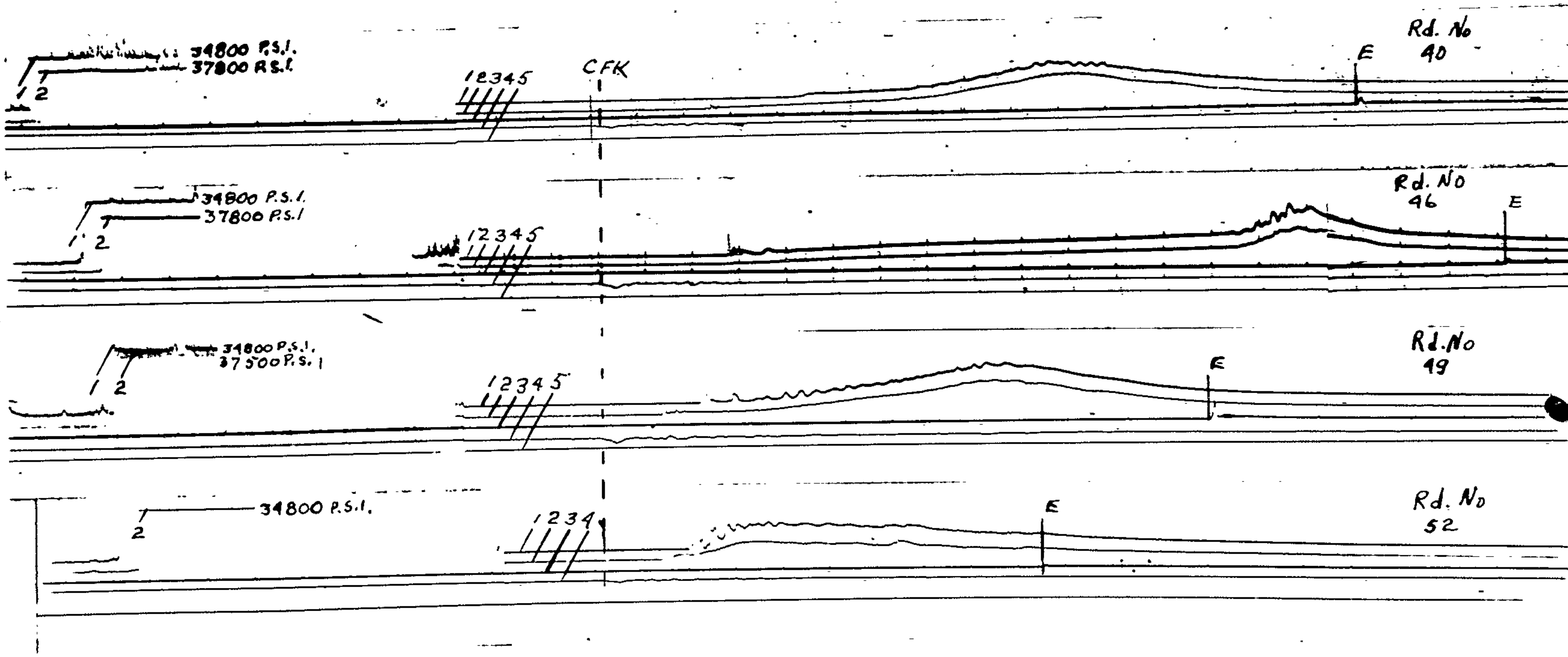


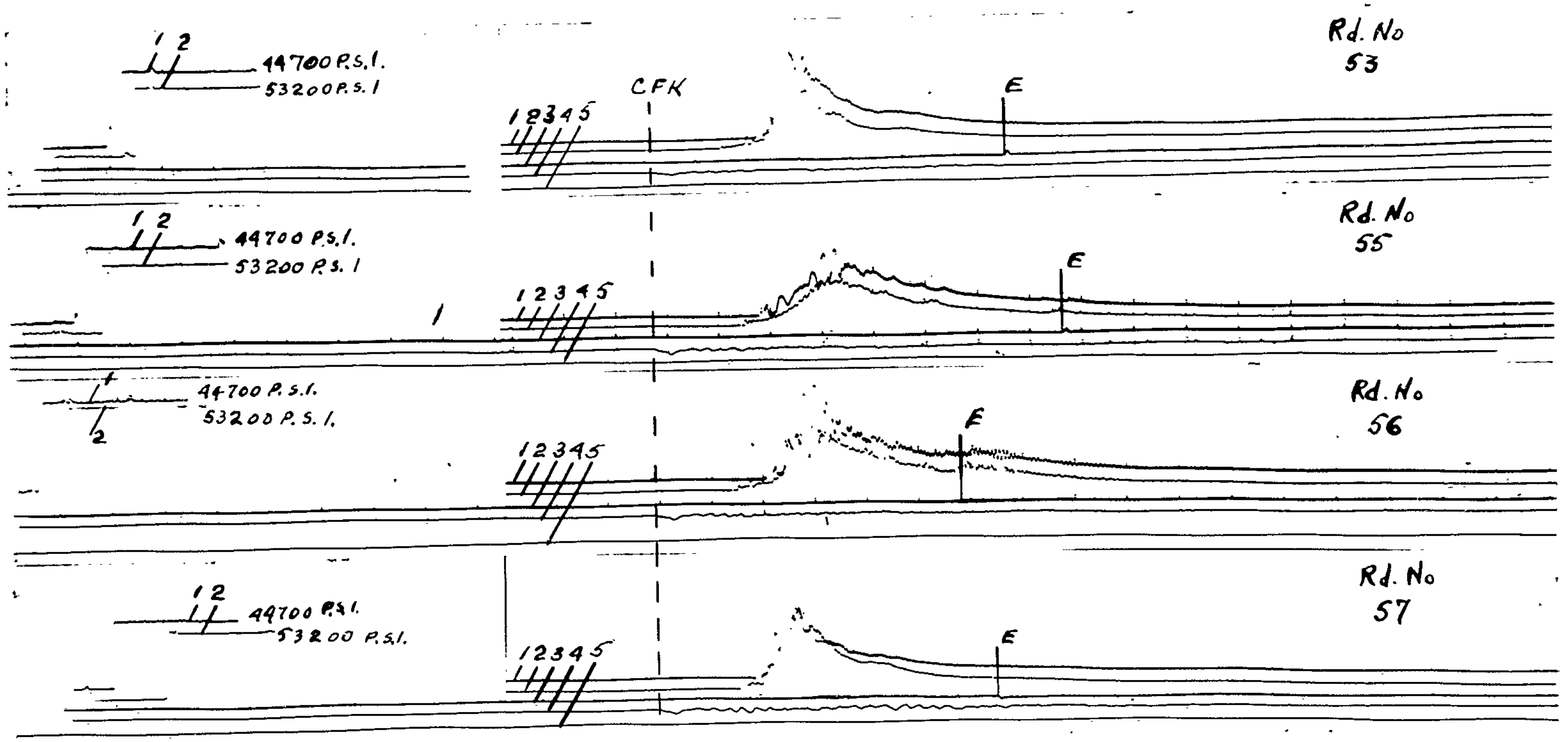
FIGURE 19

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
9/16/52	53	150 Grams	17.0%	12.6	81.4	6.0
9/18/52	55	" "	20.0%	"	"	"
"	56	" "	"	"	"	"
"	57	" "	"	"	"	"



U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
8/18/52	58	150 Grams	20.0%	12.6	81.4	6.0
"	59	" "	"	"	"	"
"	60	" "	"	"	"	"
"	61	" "	"	"	"	"

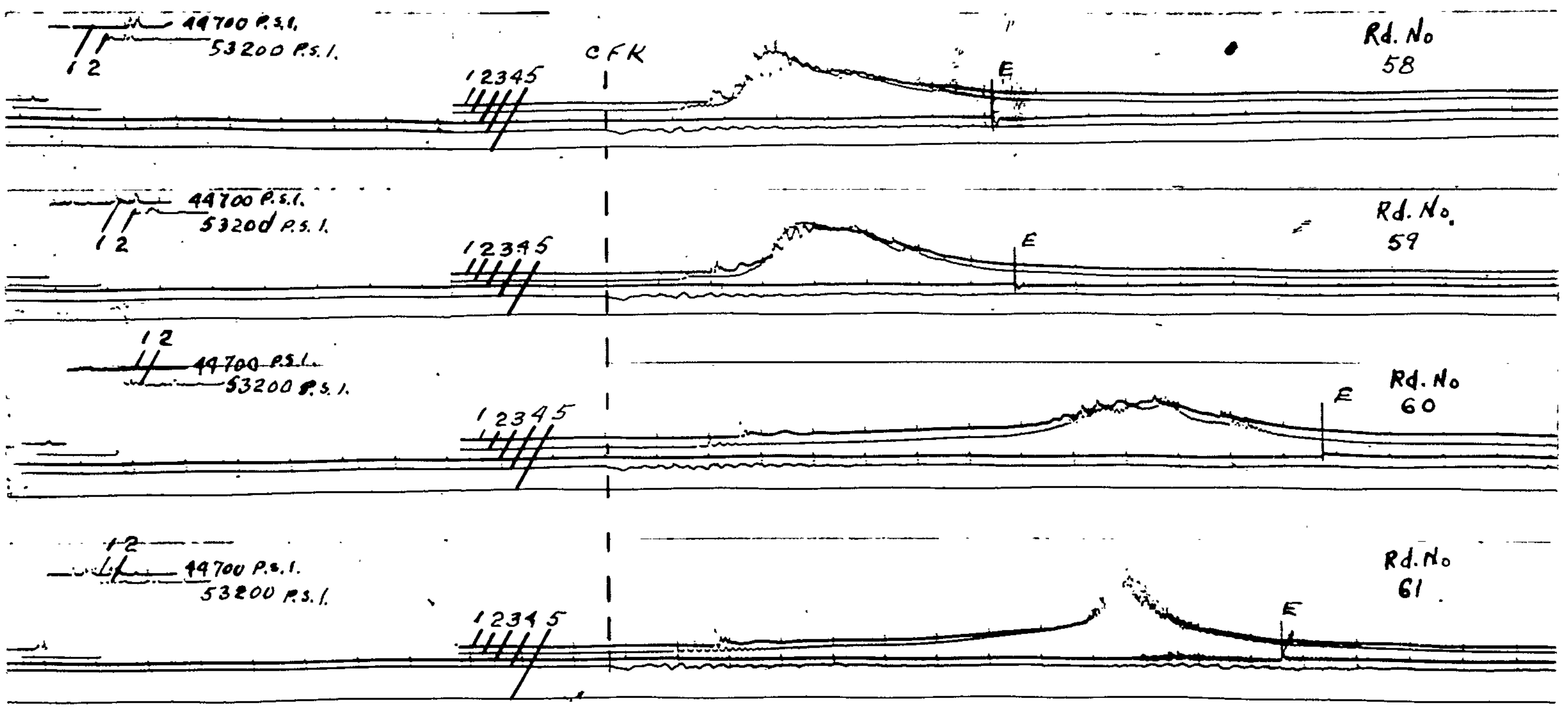


FIGURE 12

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_5	% H_2O
9/26/52	62	150 Grams	10.0%	12.6	81.4	6.0
"	63	" "	20.0%	"	"	"
"	64	" "	30.0%	"	"	"
9/29/52	68	" "	40.0%	"	"	"

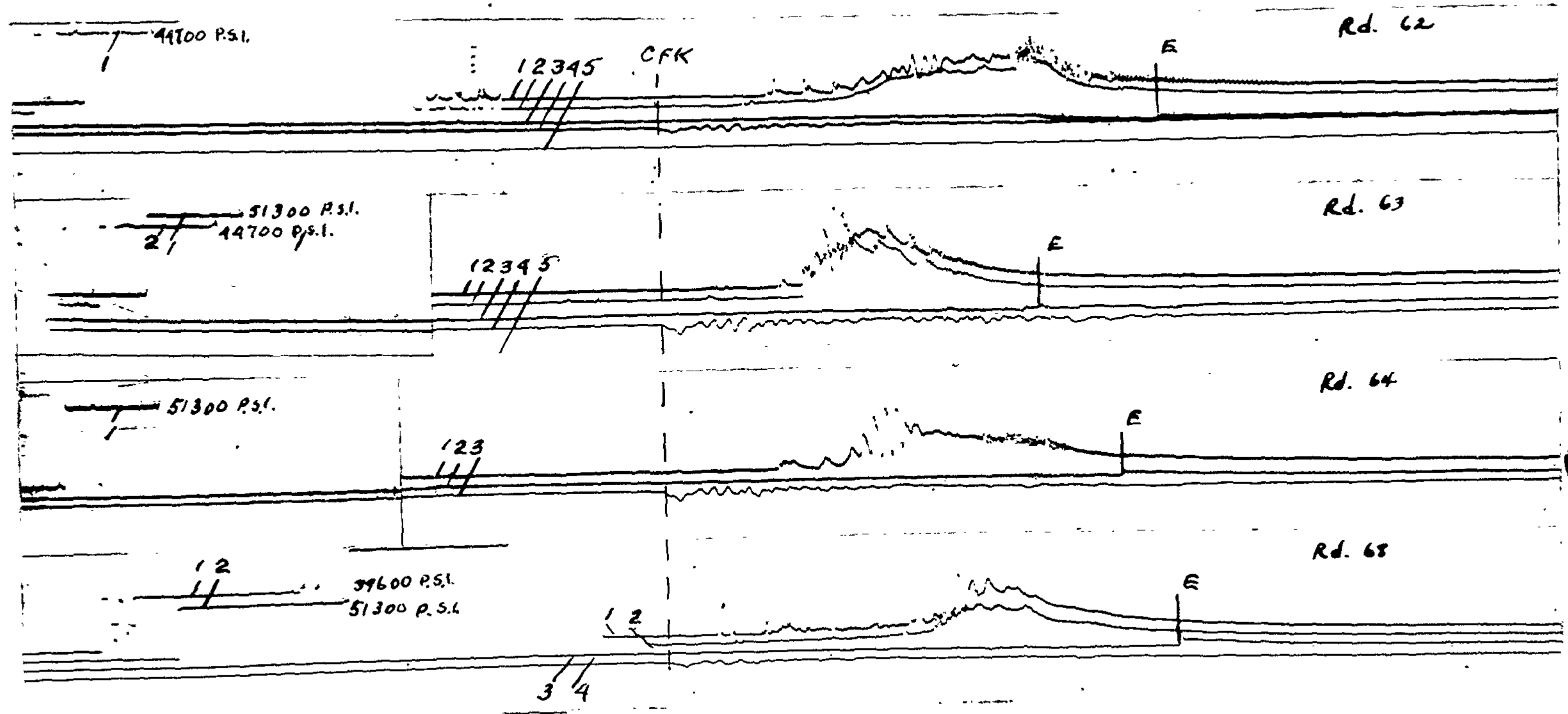


FIGURE 13

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/1/52	69	200 Grams	30.0%	12.6	81.4	6.0
"	70	225 "	"	"	"	"
"	72	275 "	"	"	"	"
"	73	300 "	"	"	"	"

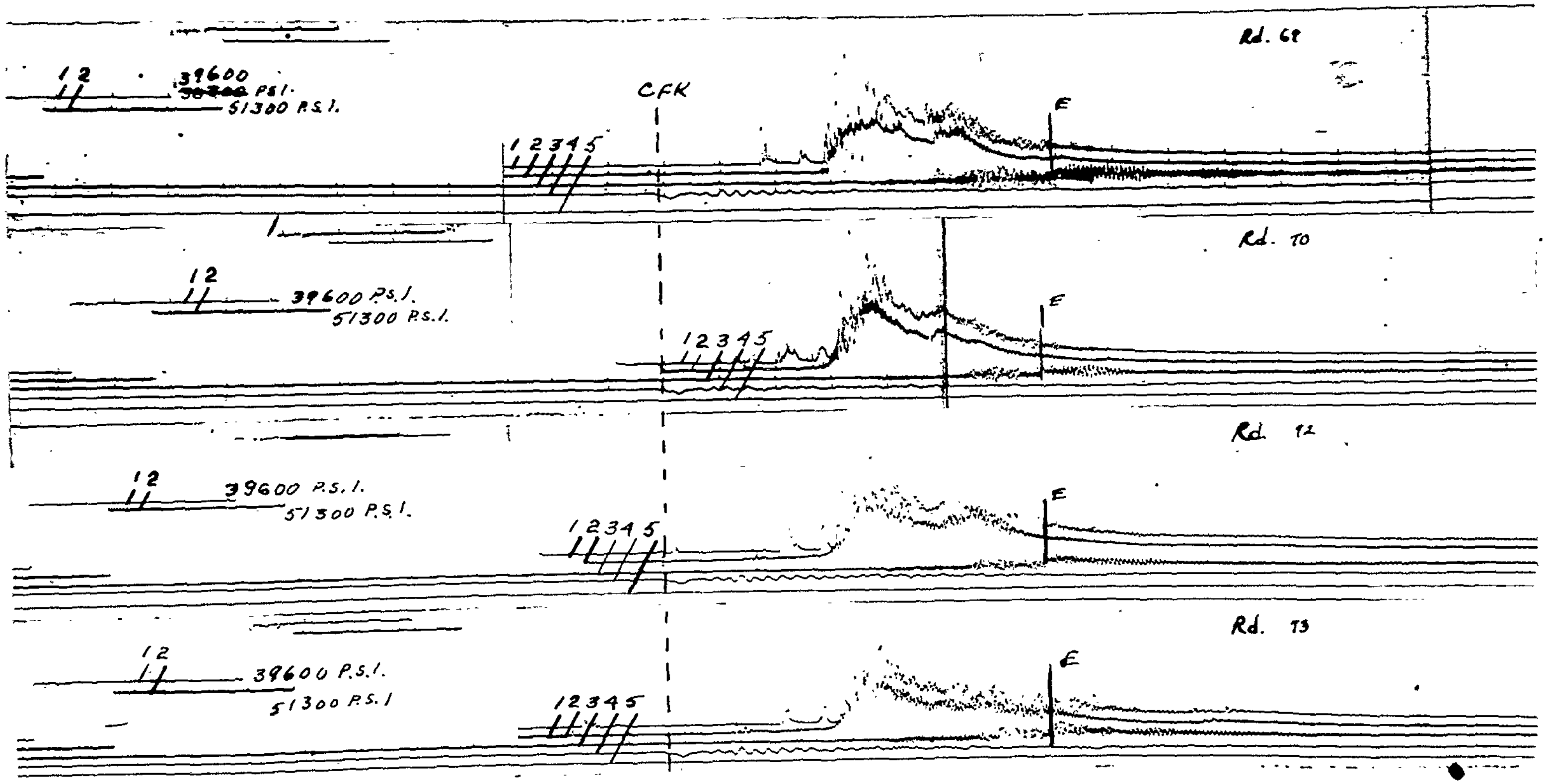


FIGURE 14

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	$N_2H_5NO_3$	% N_2H_4	% H_2O
10/2/52	74	150 Grams	30.0%	15.0	78.9	6.1
"	75	" "	"	18.0	76.2	5.8
"	76	" "	"	22.6	71.9	5.5
10/3/52	77	" "	"	15.0	78.9	6.1

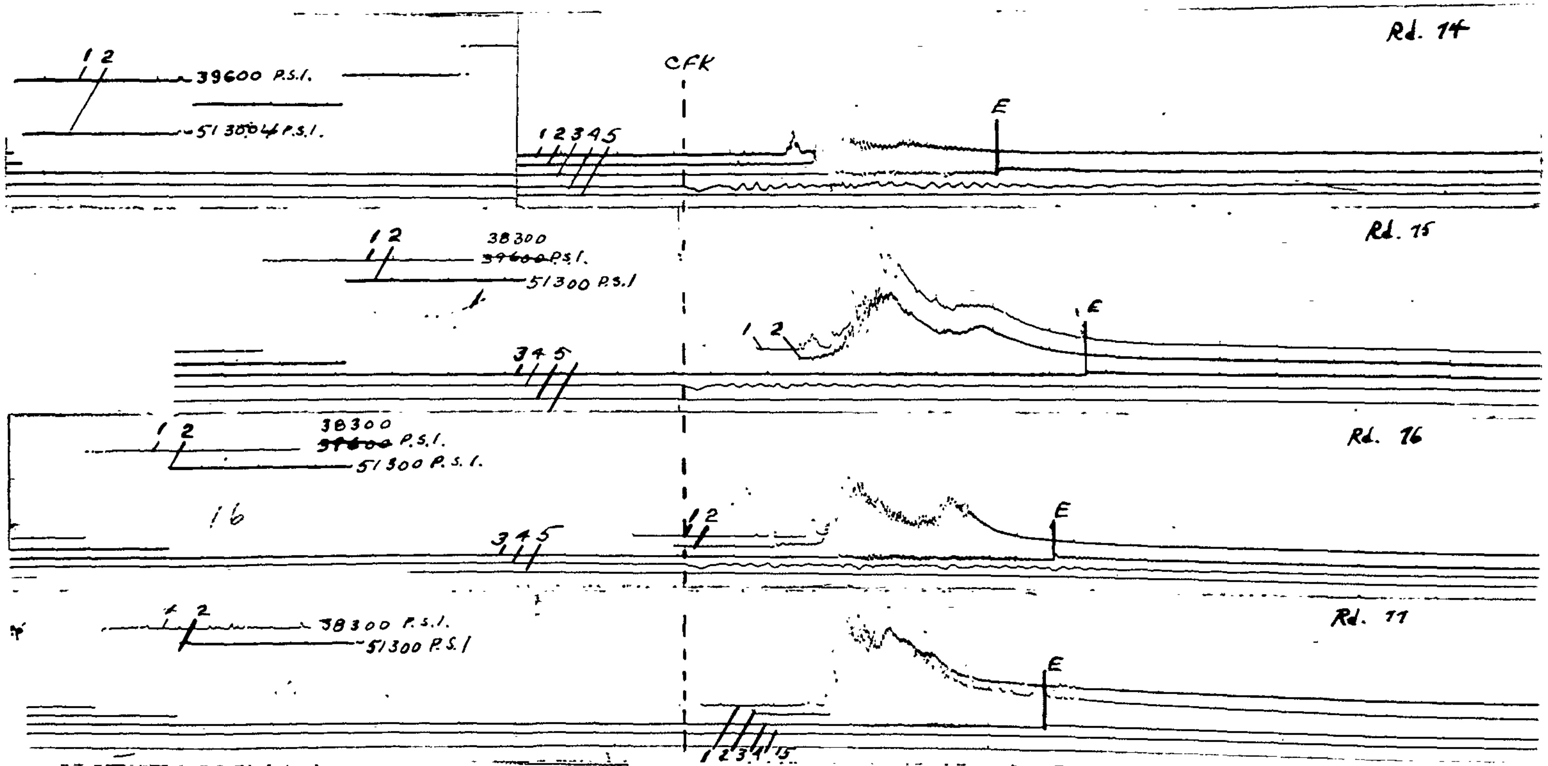


FIGURE 15

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/3/52	79	175 Grams	30.0%	18.0	76.2	5.8
"	80	200 "	"	"	"	"
"	81	225 "	"	"	"	"
"	82	250 "	"	"	"	"

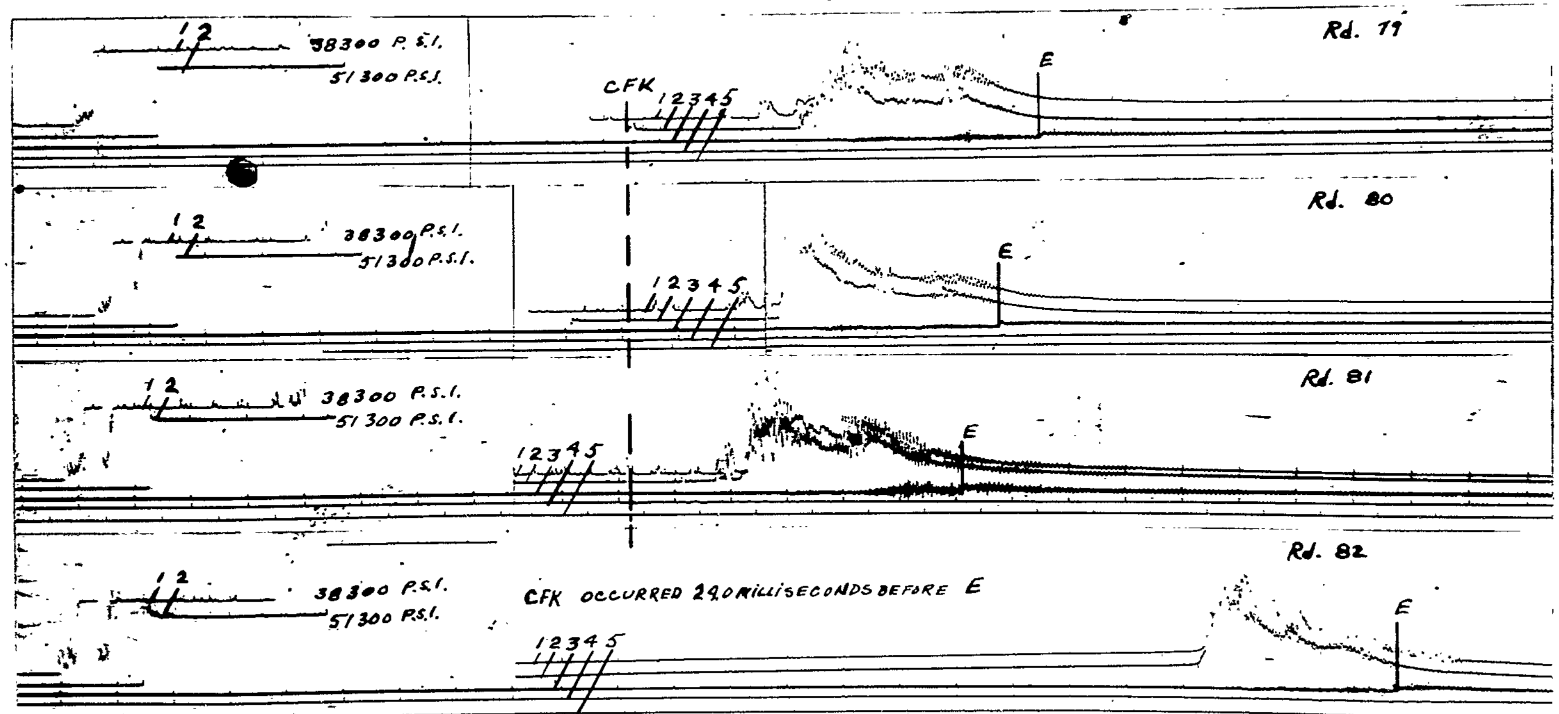

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FIGURE 16

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/8/52	85	275 Grams	30.0%	18.0	76.2	5.8
10/14/52	88	" "	10.0%	"	"	"
10/15/52	89	" "	"	"	"	"
"	90	" "	"	"	"	"

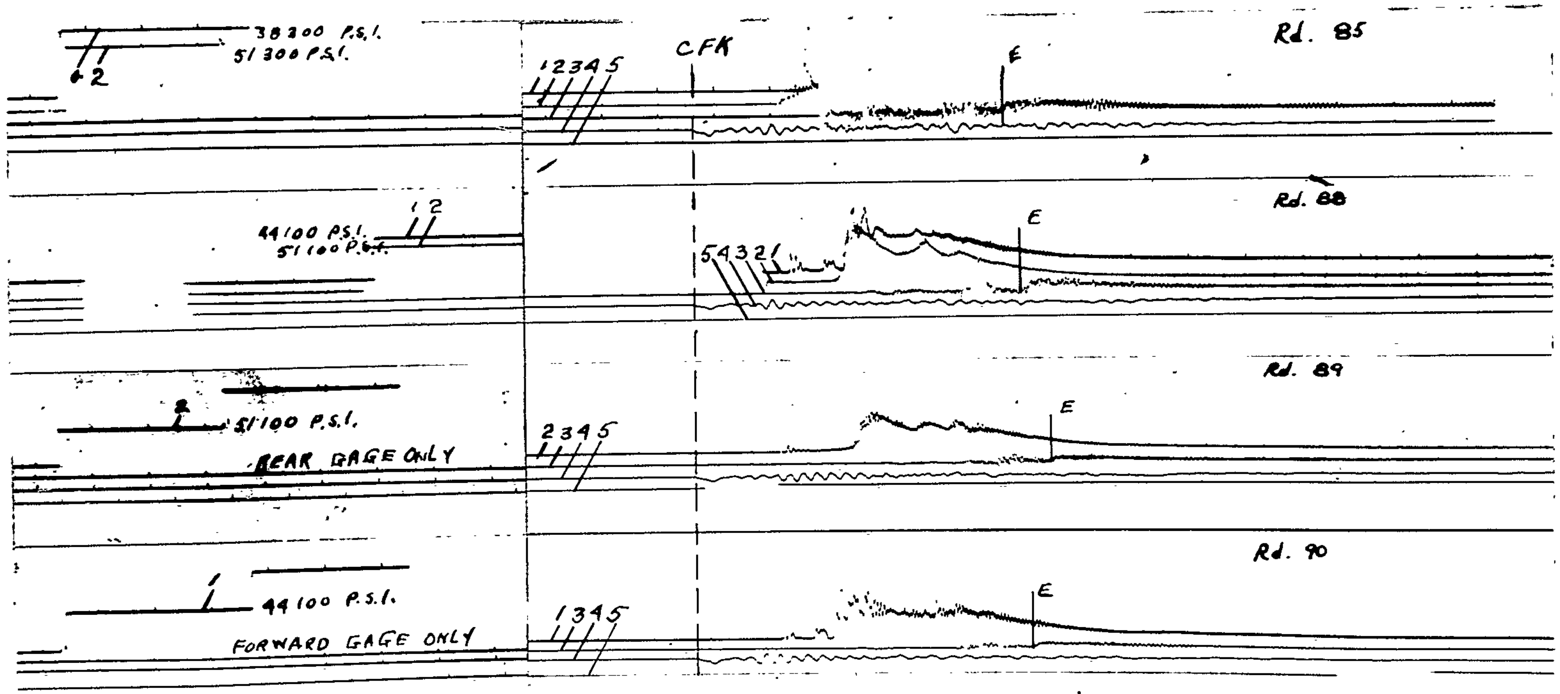

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FIGURE 17

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/16/52	91	290 Grams	10.0%	18.0	76.2	5.8
"	92	300 "	10.0%	"	"	"
"	93	275 "	30.0%	"	"	"
"	94	250 "	10.0%	15.0	78.9	6.1

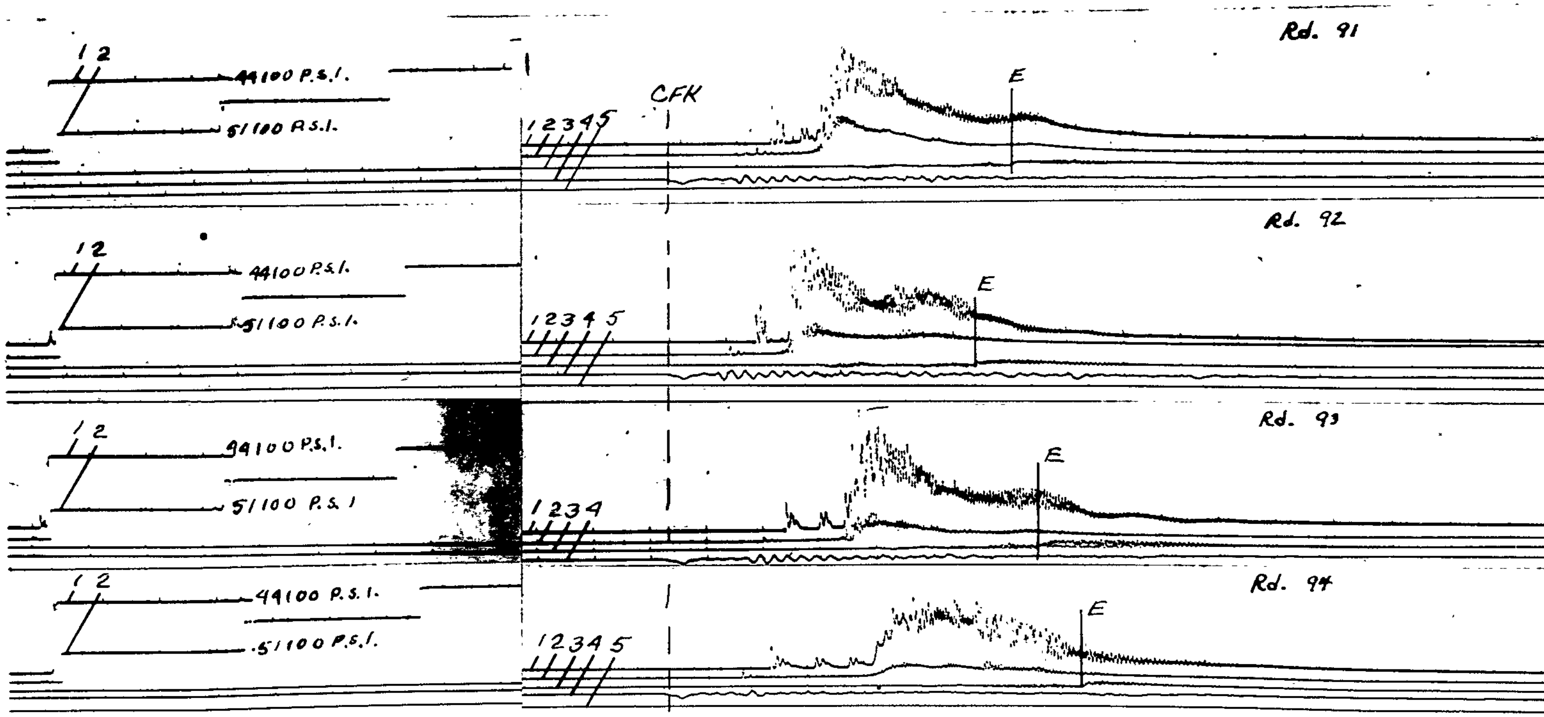

FIGURE 18

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/16/52	95	250 Grams	20.0%	15.0	78.9	6.1
"	96	" "	30.0%	"	"	"
10/22/52	99	275 "	25.0%	18.0	76.2	5.8
"	101	" "	"	"	"	"

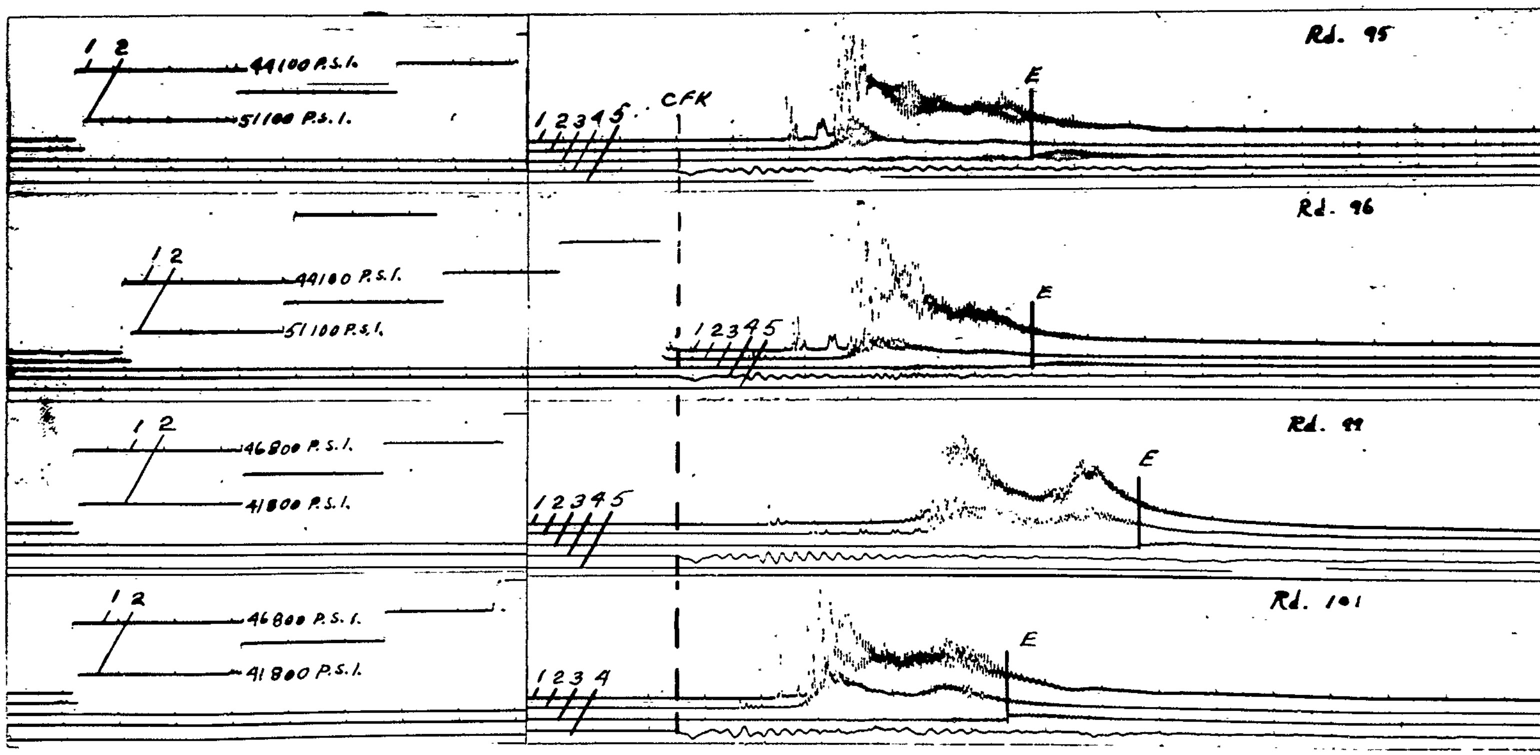

FIGURE 19

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
10/24/52	103	200 Grams	10.0%	12.0	78.0	10.0
"	104	150 "	20.0%	12.6	81.4	6.0
"	105	150 "	"	"	"	"
"	106	217.7 "	"	18.0	76.2	5.8

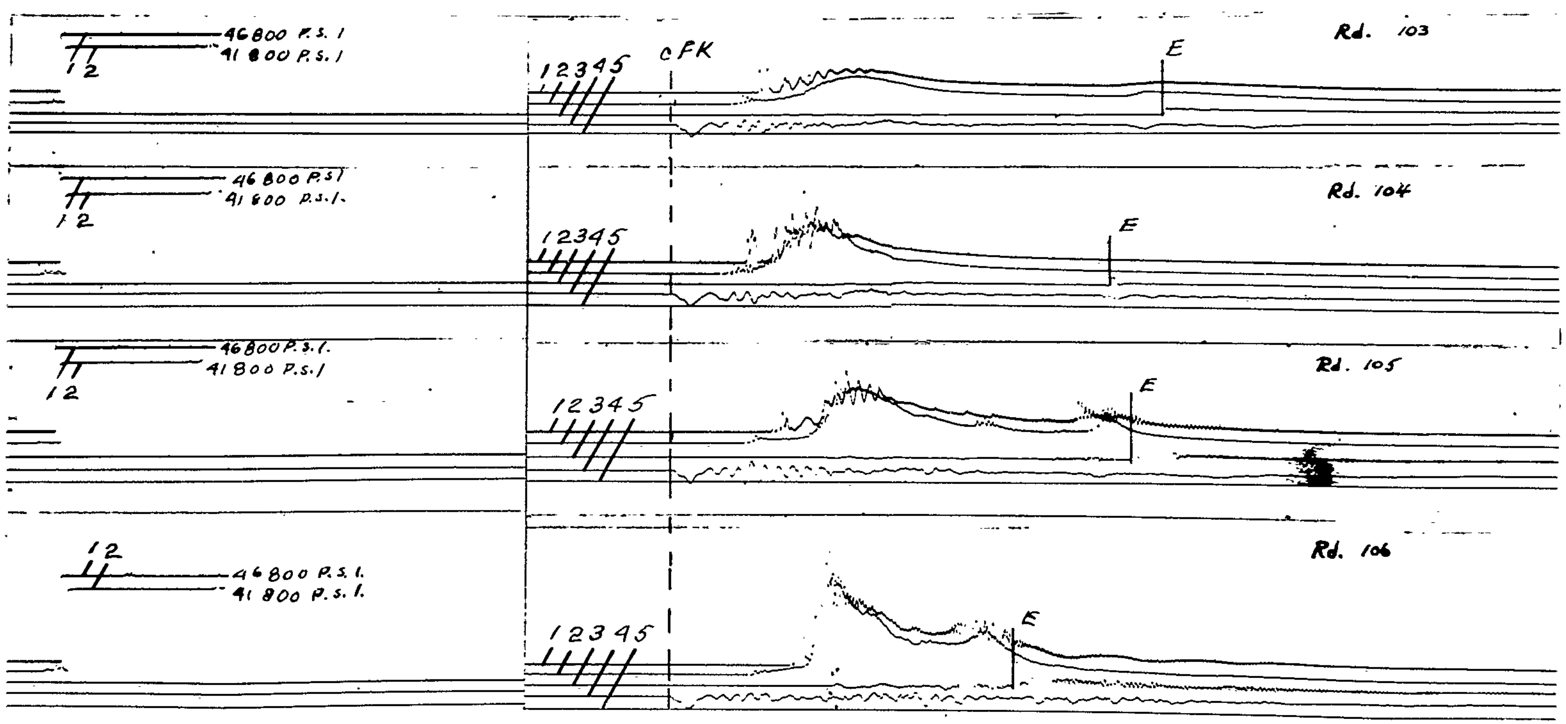

FIGURE 20

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_5	% H_2O
10/27/52	107	217.7 Grams	20.0%	18.0	76.2	5.8
10/29/52	109	222.9 "	16.5%	17.6	74.4	8.0
"	110	227.9 "	15.2%	17.2	72.8	10.0
11/6/52	111	250 "	10.0%	15.0	80.5	4.5

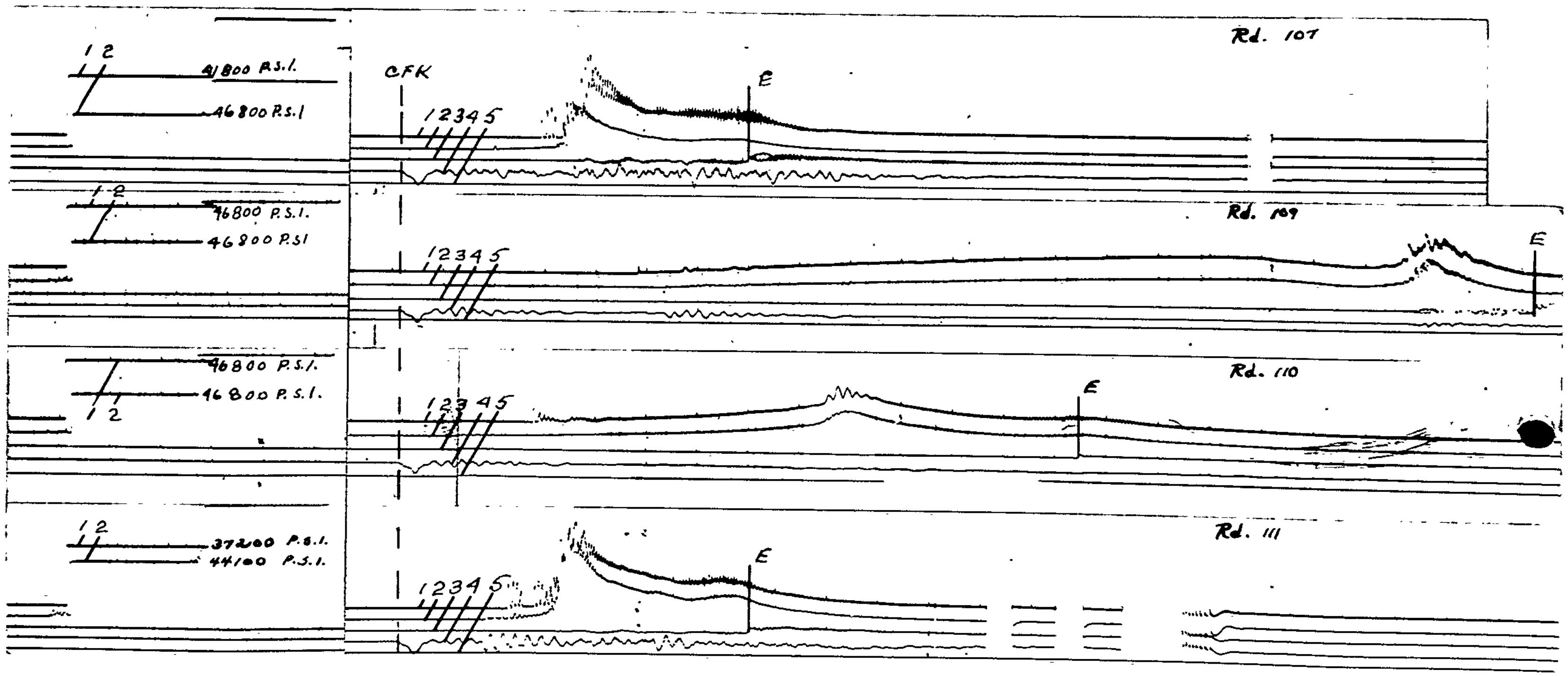

FIGURE 22

Figure 21

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/6/52	112	250 Grams	5.0%	15.0	80.5	4.5
11/7/52	113	" "	1.0%	"	"	"
11/13/52	114	" "	"	18.0	76.2	5.8
"	115	" "	"	15.0	80.5	4.5

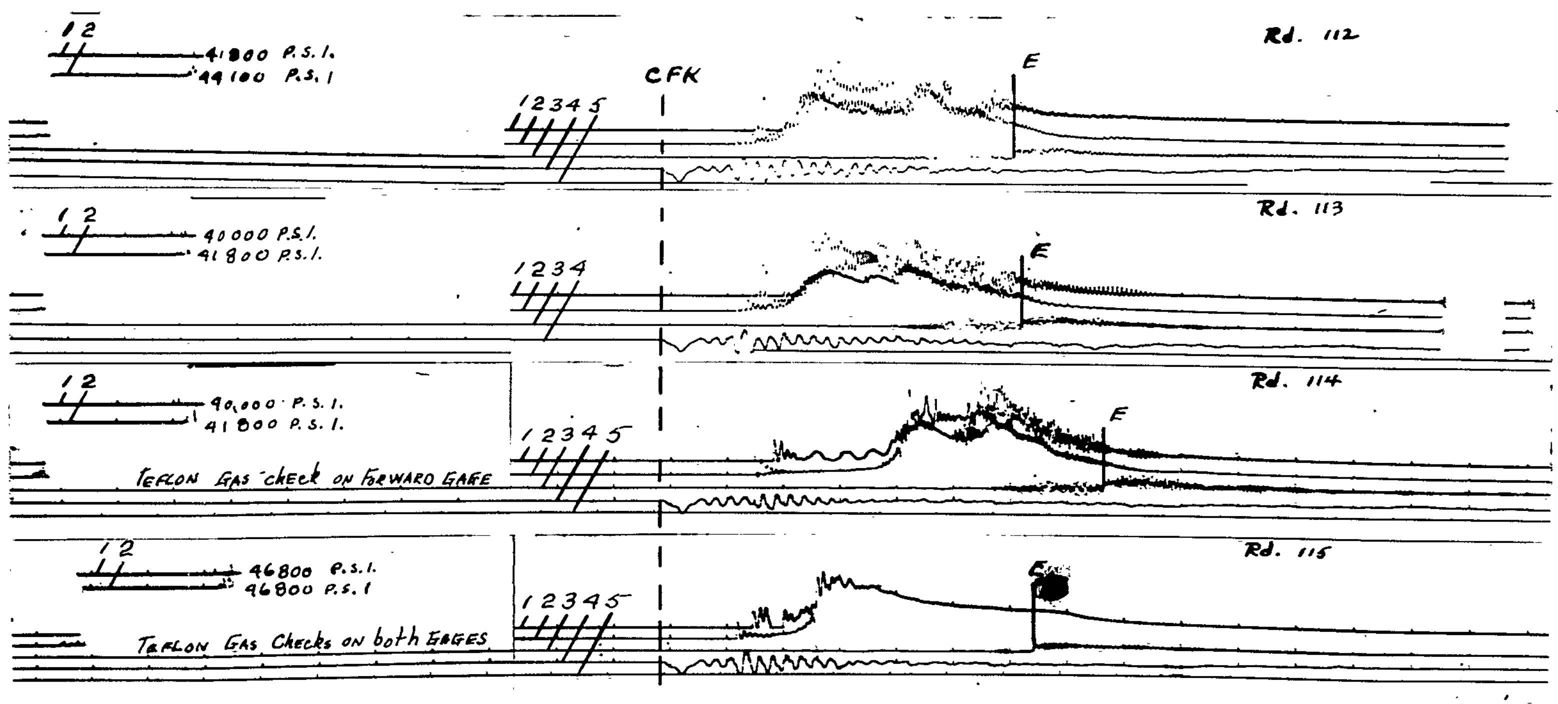

FIGURE 22

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/18/52	116	275 Grams	1.0%	15.0	80.5	4.5
"	117	300 "	1.0%	"	"	"
"	118	250 "	.8%	18.0	76.2	5.8
"	119	275 "	2.6%	"	"	"

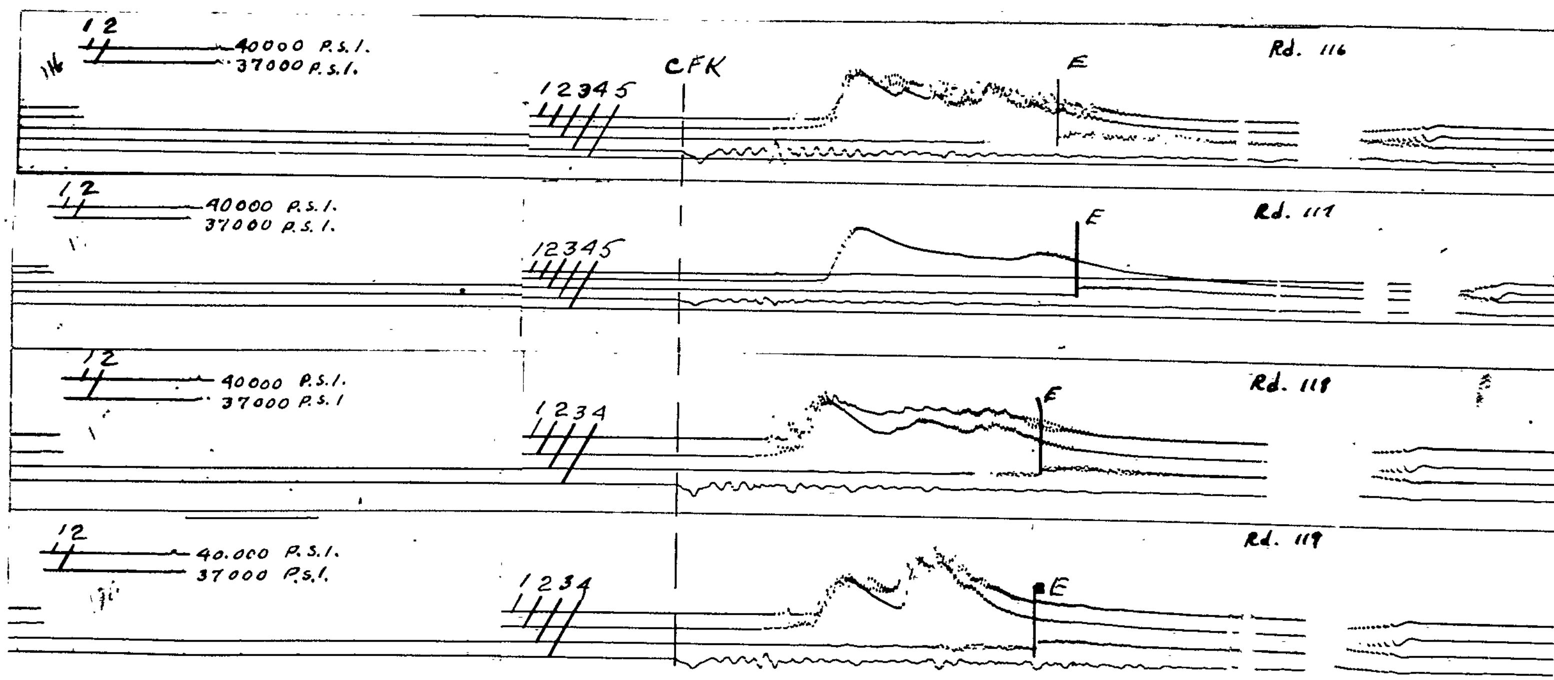

FIGURE 23

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PRESSURE-TIME OSCILLOGRAMS

Date	Round No.	Charge Weight	Free Volume	% $N_2H_5NO_3$	% N_2H_4	% H_2O
11/18/52	120	300 Grams	2.20%	18.0	76.2	5.8
11/19/52	122	250 "	.8%	22.6	72.9	9.3
"	124	300 "	2.2%	"	"	"
"	125	325 "	.8%	"	"	"

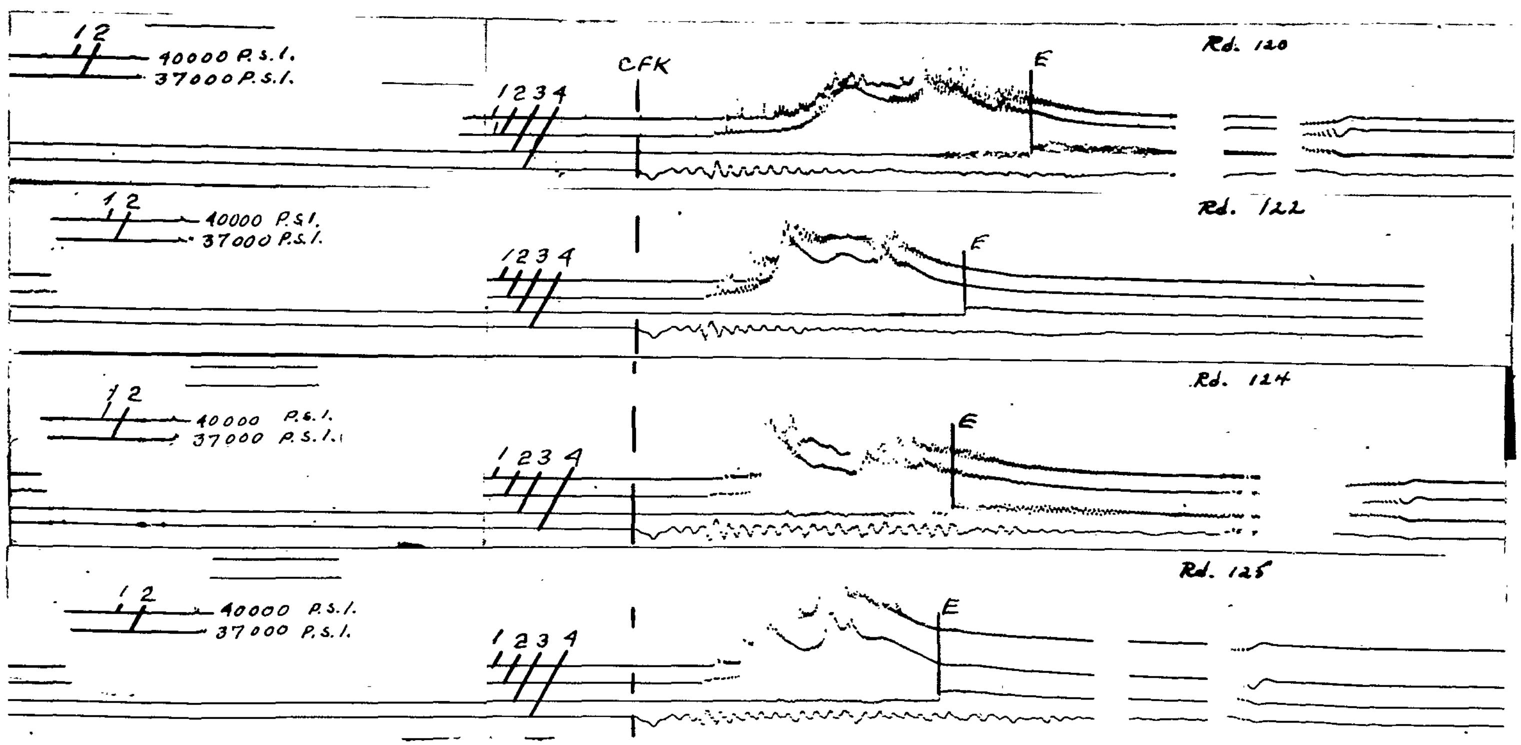

FIGURE 24

NP9-62860

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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

PEAK PRESSURE VS % FREE VOLUME

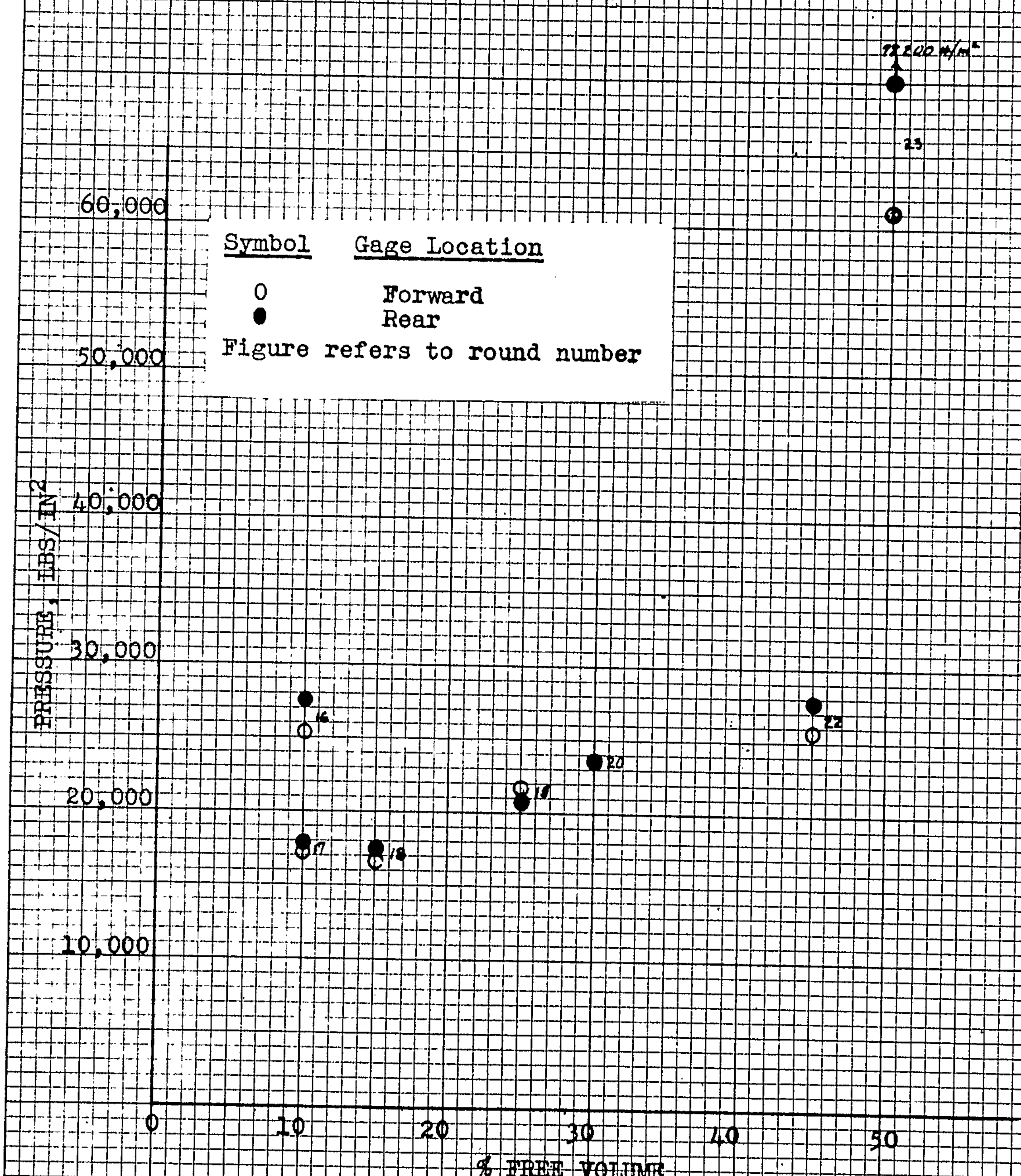

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Figure 25

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION

Liquid Propellants Section

VELOCITY VS % FREE VOLUME

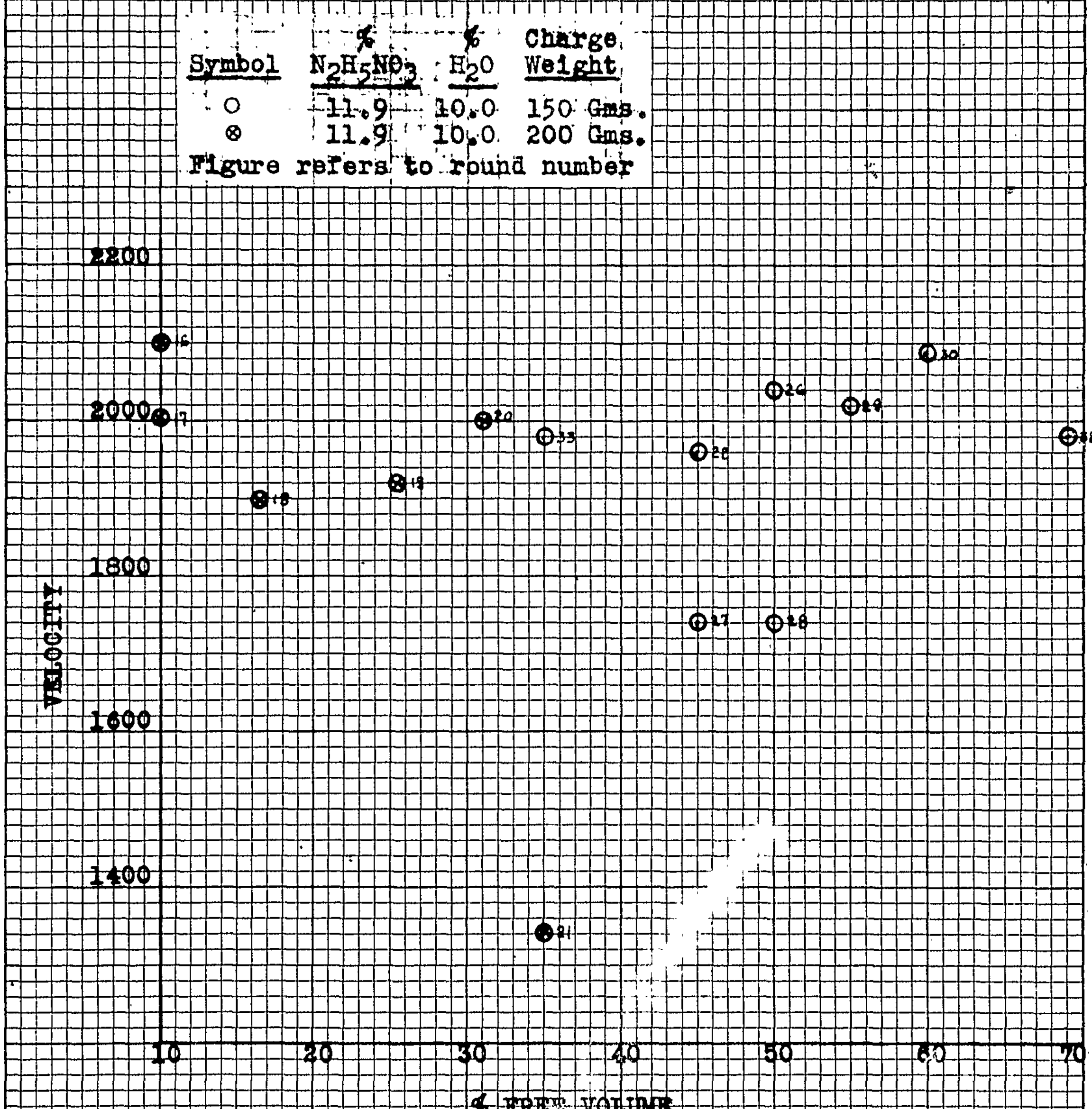
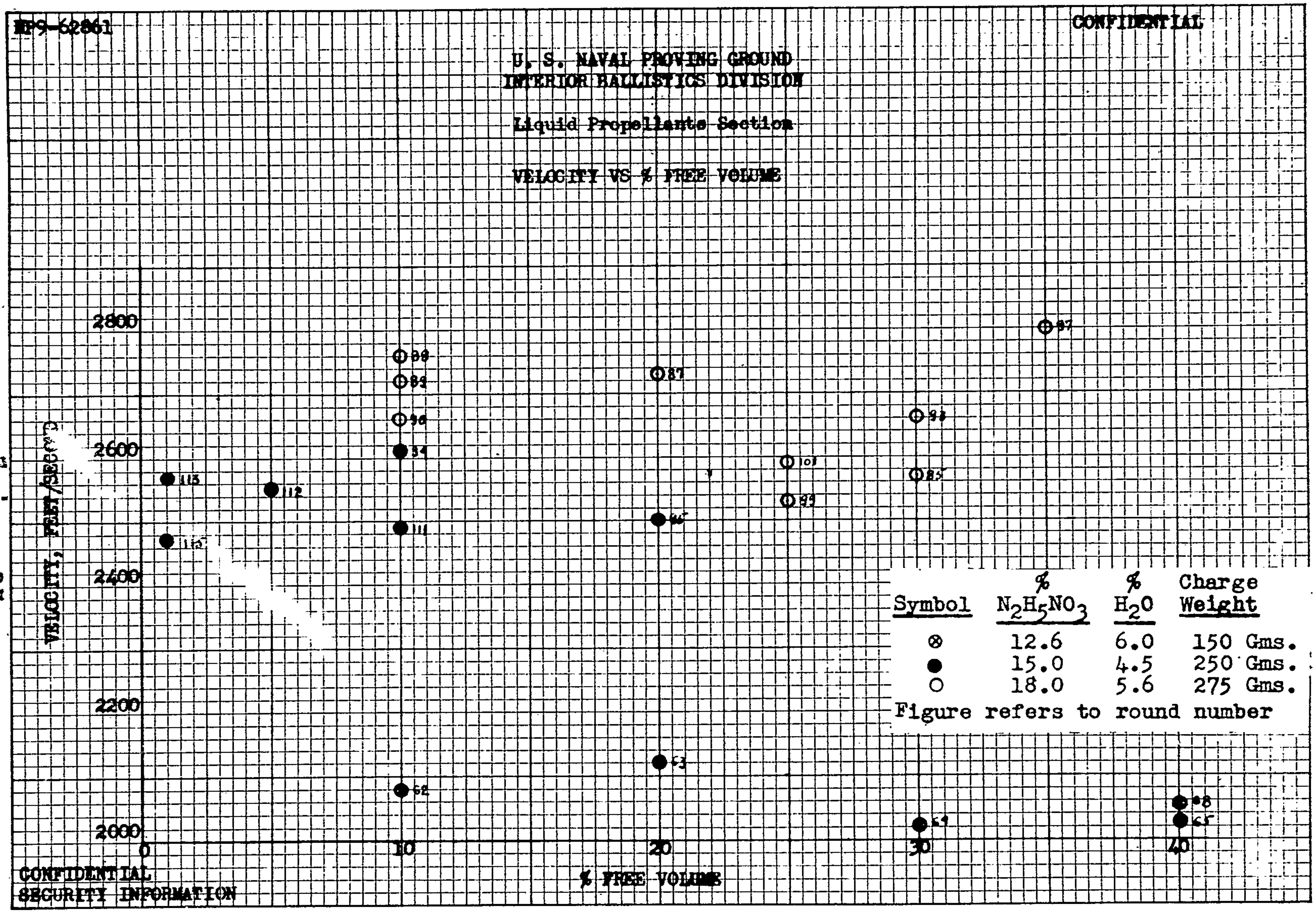


Figure 26



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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
Liquid Propellants Section
VELOCITY VS % FREE VOLUME
VELOCITY, FEET/SECOND
2000
2200
2400
2600
2800
0
10
20
30
40
% FREE VOLUME
Symbol
% $N_2H_5NO_3$
% H_2O
Charge Weight
⊗ 12.6 6.0 150 Gms.
● 15.0 4.5 250 Gms.
○ 18.0 5.6 275 Gms.
Figure refers to round number
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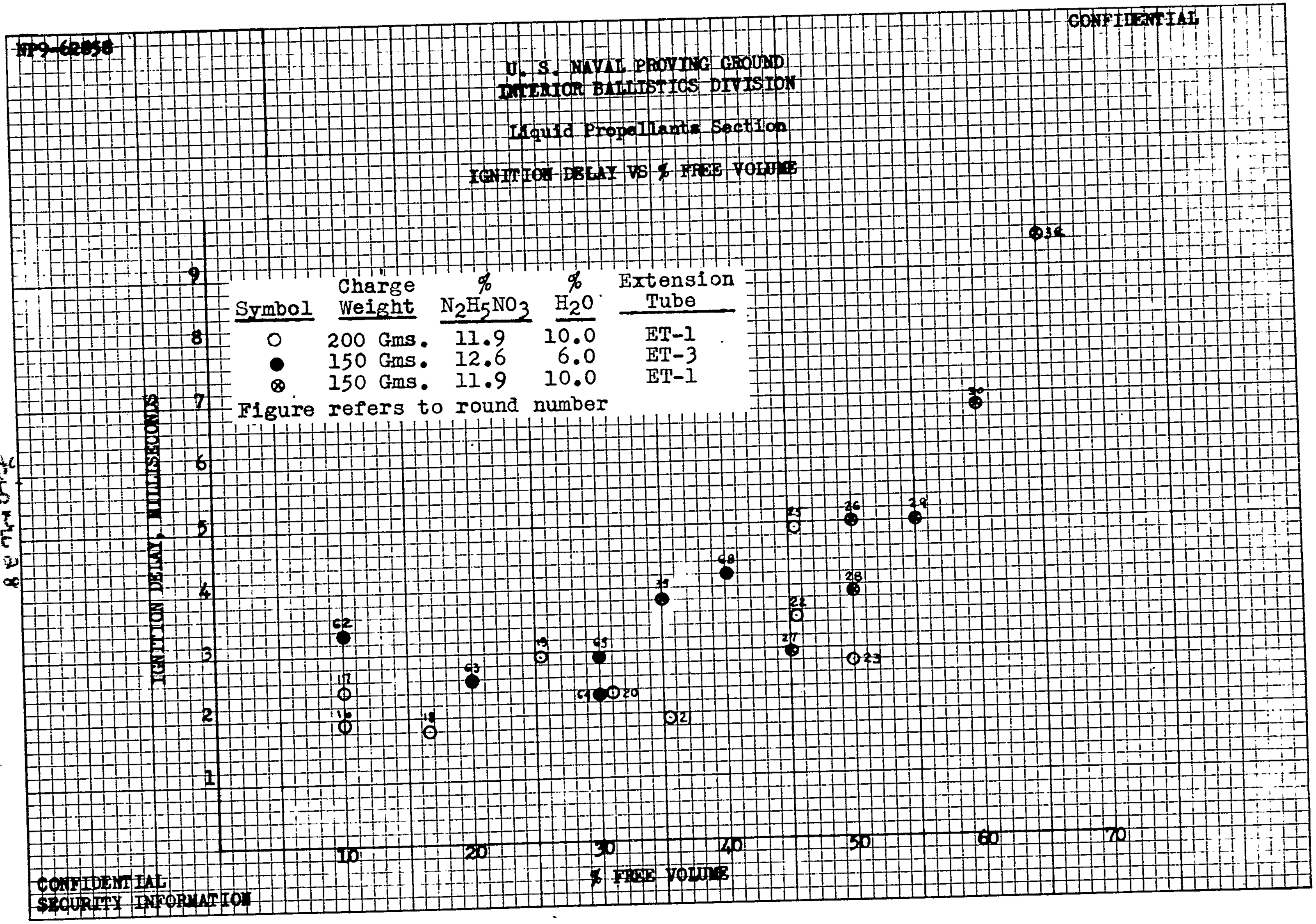
Figure 27


NP9-62858
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U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
Liquid Propellants Section
IGNITION DELAY VS % FREE VOLUME
Symbol | Charge Weight | % $N_2H_5NO_3$ | % H_2O | Extension Tube
○ 200 Gms. 11.9 10.0 ET-1
● 150 Gms. 12.6 6.0 ET-3
⊗ 150 Gms. 11.9 10.0 ET-1
Figure refers to round number
IGNITION DELAY, MILLISECONDS
% FREE VOLUME
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SECURITY INFORMATION

Figure 38

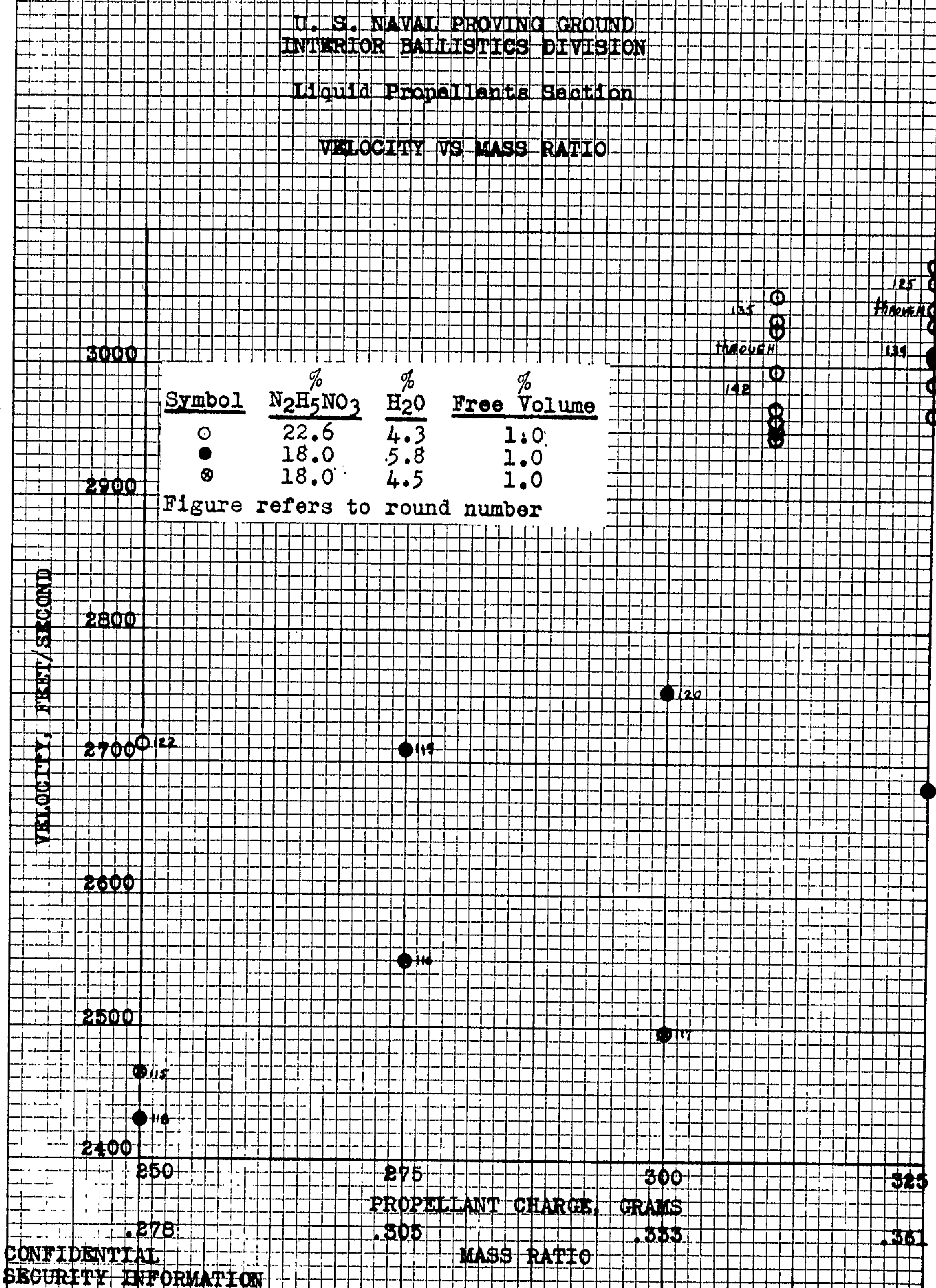
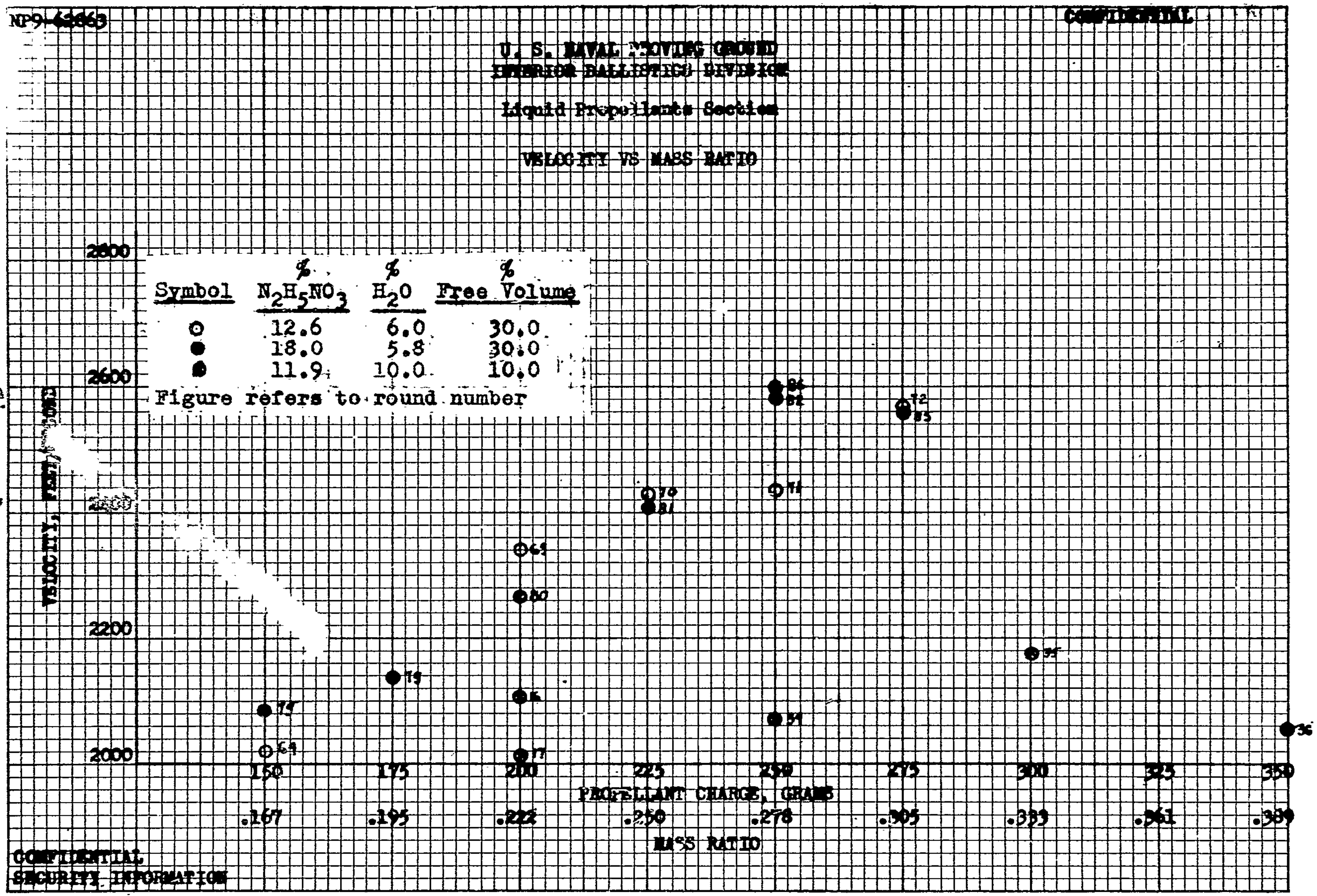

U. S. NAVAL PROVING GROUND
INTERIOR BALLISTICS DIVISION
Liquid Propellants Section
VELOCITY VS MASS RATIO
Symbol % N2H5NO3 % H2O % Free Volume
22.6 4.3 1.0
18.0 5.8 1.0
18.0 4.5 1.0
Figure refers to round number
VELOCITY, FEET/SECOND
3000
2900
2800
2700
2600
2500
2400
250
275
300
325
PROPELLANT CHARGE, GRAMS
.278
.305
.333
.361
MASS RATIO
135
THROUGH
142
125
THROUGH
134
122
119
120
121
116
117
115
118

Figure 29


NP9-62663
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INTERIOR BALLISTICS DIVISION
Liquid Propellants Section
VELOCITY VS MASS RATIO
Symbol | % $N_2H_5NO_3$ | % H_2O | % Free Volume
○ | 12.6 | 6.0 | 30.0
● | 18.0 | 5.8 | 30.0
● | 11.9 | 10.0 | 10.0
Figure refers to round number
VELOCITY, FEET/SECOND
2800
2600
2400
2200
2000
150
175
200
225
250
275
300
325
350
PROPELLANT CHARGE, GRAMS
.167
.195
.222
.250
.278
.305
.333
.361
.389
MASS RATIO
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Figure 30

TABLE II

Primer Design Effect on Ignition Delay

Round No.	Free Volume	Charge Weight	% $N_2H_5NO_3$	% N_2H_4	% H_2O	Extension Tube	Diaphragm Thickness	Ignition Delay
15	10%	200 Grs.	12.0	78.0	10.0	ET-2	.003	misfire
53	17%	150 "	12.6	81.4	6.0	"	.006	2.0
57	20%	" "	"	"	"	"	.004	1.6
54	"	" "	"	"	"	"	.003*	misfire
58	"	" "	"	"	"	ET-3	.025	1.4
59	"	" "	"	"	"	"	.020	2.6
60	"	" "	"	"	"	"	.015	7.6
61	10%	" "	"	"	"	"	"	6.0
38	"	" "	11.9	78	10	"	.008	misfire

* .003" thick with a small pinhole plugged with wax

TABLE III

Approximate Free Volume for Various Caliber Guns

Gun Type	Approximate Chamber Volume	Approximate Solid Propellant Charge	Approximate Liquid Propellant Charge	Free Volume	Liquid Propellant Charge for 10% Free Volume
20mm	2.9 in^3	0.095 lbs.	0.095 lbs.	10	0.095 lbs.
40mm	28 in^3	0.66 "	0.66 "	35	0.92 "
3"/50	222 in^3	4.5 "	4.5 "	44	7.4 "
5"/38	650 in^3	15.5 "	15.5 "	34	21.5 "
5"/54	800 in^3	18.5 "	18.5 "	36	26.4 "
6"/47	1470 in^3	32.0 "	32.0 "	40	48.5 "
8"/55	3370 in^3	75.0 "	75.0 "	38.5	111.0 "

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